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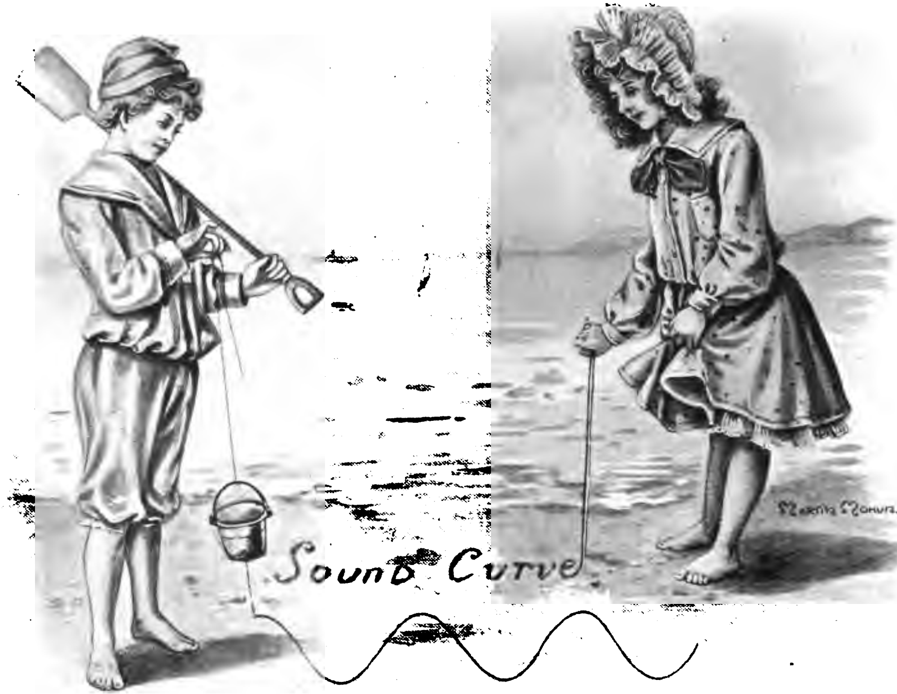
With the Writer's
Kind regards.

SOUND AND RHYTHM



DRAWING SOUND CURVE (SEE P. 23)

SOUND AND RHYTHM

BY

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PREFACE

THE time and care so wisely given in primary schools to the teaching of singing suggest that in them should be taught also the beautiful mechanism of sound and hearing, and for this another reason can be found. During the Boer War it was said that our young soldiers, when separated from their officers, showed at times a lack of intelligent initiative. This may have been in part due to the too literary character of their education. Be that as it may, all will agree that children should be taught to observe and think for themselves. The phenomena of sound afford a good means of doing this. The objection that no time can be found may be met by proposing that 'analysis' and 'parsing' should give way. More trouble is caused in the world by bad physiology than by bad grammar.

To make the subject as simple as possible, special attention has been paid to the illustrations; also models of the ear have been prepared. These are of

natural size, except in the case of the small bones, which are enlarged five times.

The models and most of the drawings were made by Mr. Lapidge. For the figure subjects we are indebted to the facile pen of Miss Martin Mohun.

W. E.

DEVONSHIRE PLACE, LONDON, W
November, 1905.

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SOUND AND RHYTHM

CHAPTER I

NATURE OF SOUND

PRODUCTION OF SOUND: TRANSMISSION OF SOUND

NEARLY all sounds are produced by vibrations in the air around us. What happens when a tuning-fork is sounded is that the prongs vibrate, the vibrations are communicated to the air, they spread through it, and thus reach our ears, parts of which in their turn are made to vibrate. That the sound produced by a tuning-fork is due to vibrations seems to be pretty clearly shown by four facts: firstly, that we can feel the fork vibrating as we hold it in our fingers; secondly, that as the vibrations diminish in strength the sound dies down; thirdly, that if we suddenly stop the vibrations by touching the prongs the sound also stops; fourthly, that if a sounding tuning-fork be made to touch a bead hanging by a thread the bead is knocked away (Fig. 1).

That sound is conveyed by the air is most conclusively shown by the use of the air-pump. If an alarum clock is placed under the bell-glass of an air-

pump and the air pumped out the alarum cannot be heard; if air is readmitted then it can be again heard (Fig. 2).

But to produce sound it is necessary that the waves in the air should not be too few or too frequent. If they are fewer than about twenty, or more frequent than 20,000 a second, we hear nothing. Some people, who are not in any degree deaf, can pass through a field of chirping grasshoppers and not hear them. This is because the frequency of the shrill notes the

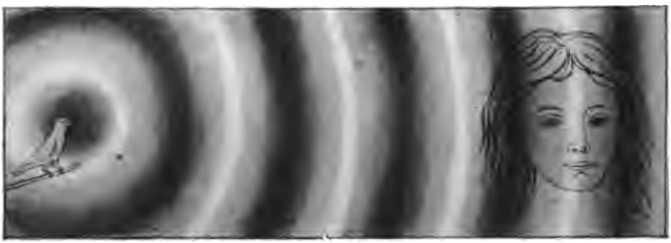


FIG. 1.—SOUND-WAVE SPREADING FROM SOURCE.
To show waves of sound spreading from canary.

grasshoppers produce is too great for their ears to hear.

It is a matter of common observation that sound takes an appreciable time to travel. A flash of lightning is seen some little time before the peal of thunder is heard; the flash of a distant cannon is seen before the report is heard. If we know our distance from the cannon we can get some idea of the rate sound travels at, but any wind blowing at the time will affect the result. Also the temperature makes a difference; sound travels a little faster on a warm day because the air is less dense.

Accurate observations give the rate sound travels at when there is no wind and the temperature is at the freezing-point of water as 1,090 feet a second, or a mile in 4·8 seconds. If, therefore, five seconds elapse between a flash of lightning and the peal of thunder, we may infer that the centre of the storm is about a mile away. This rate is twelve times as fast as an

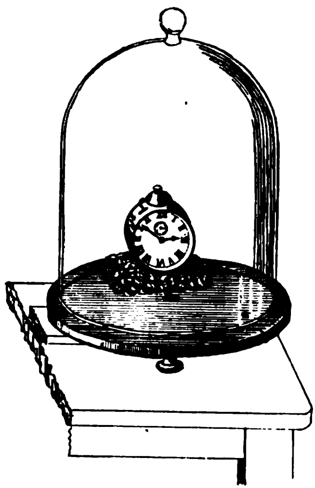


FIG. 2.—AIR-PUMP EXPERIMENT.

Bell of air-pump with alarum clock ; the pump itself is not shown.

express train, but not so fast as the projectiles from high velocity guns. During the Boer War it was not uncommon for a soldier to hear the explosion of a shell near him, and a little later the report of the firing of the gun in the distance.

Sound travels the same pace on the tops of mountains as at the sea-level, but there being fewer particles of air,

there is less weight in the vibrations and the sounds are not so loud ; this is in accord with the air-pump experiment.

All sounds, whether shrill or deep, travel at the same pace : if they did not, the music of a band at a distance would be a mere confused noise.

The immense distance that sound can travel was shown at the great eruption which occurred in 1883 in the volcanic island of Krakatoa, when a large part of a mountain was blown into the air. Krakatoa lies in the Sunda Straits, between Java and Sumatra, and the report of the eruption could be heard 2,000 miles away, as far as the Indian Ocean, where it was thought to be the firing of heavy guns, so that from various ports steamers were sent out in search of ships supposed to be in distress. The sound was heard over a thirteenth of the entire surface of the earth—that is to say, over an area equal to Europe and Africa together. Further, the waves of air, although no longer audible, travelled, as shown by recording barometers, completely round the earth, meeting at the antipodes of Krakatoa ; the sound took about eighteen hours to go half round the world. The rate of movement must have been affected by the trade winds, but these are fairly steady. When allowance was made for their force and direction, it was found that the calculated times agreed very closely with the times recorded on the barometers at various places.

Sound can not only travel in air and other gases, but also in liquids and solids.

That sound can travel in water is shown by putting the head under water in a bath ; a sound made by striking a penny against the side can be heard quite

well. The same thing is shown by the following experiment: to the end of the handle of a tuning-fork fasten by some beeswax a penny-piece, making a sort of foot to the fork. Place a tumbler full of water on a table, sound the fork, and while it is sounding place it so that the penny-piece at its foot is on the surface of the water. The result will be that the sound is louder. What happens is that the vibrations of the tuning-fork are conveyed through the water to the table, and the table acts as a sounding-board. The use of the penny is to bring a larger vibrating surface in contact with the water. If only the tip of the handle of the fork is put into the water, the sound is not so loud: this, in fact, is why discs are so common in sound instruments. The head of a drum, the metal plate of a telephone, the glass diaphragm of a phonograph, the drum or membrane of the ear, all exist to afford a larger surface to give out or take up the vibrations of sound.

The rate at which sound travels in water was investigated experimentally on the Lake of Geneva in 1826. A bell was struck under water, and the sound was listened to nine miles away through a trumpet, one end of which was placed under the surface of the water. The rate sound travels at in water was found to be 4,700 feet a second, or four times as fast as in air.

This transmission of sound by water is of much importance—not to fish, for it is said that they cannot hear—but to sailors. A bell rung under water from a lightship can be heard with suitable apparatus on a ship seven or more miles away; the advantage of this in a fog is obvious.

Sound, too, is conveyed by solids. By putting the

ear to a telegraph-post the sound produced by the wind on the wires overhead is heard conveyed by the post. Again, if the mouth be widely opened and a watch be half inserted, its ticking will be but faintly heard. If now the teeth are closed on the watch, the sound will be much louder; the vibrations are now conveyed through the upper teeth and the bones of the head to the deeper parts of the ears.

That solids can convey sounds is also shown by the toy (mechanical) telephone. This consists of a short tube of cardboard, or indeed of any substance, of a size to fit over the ear. At one end of the tube is fastened a cap of parchment, and through the centre of this is passed a string many yards long; at the other end of this string is fixed another similar tube. If now the string is pulled taut, and one of the telephones is spoken into, the voice can be well heard by the ear applied to the other, although the distance be considerable.

It will be convenient to describe here the electric telephone, in which the sound is conveyed, not by mechanical, but by electric, waves. The principle on which the telephone depends is that the vibrations of a thin metallic disc close to a magnet induce electric currents in the magnet. In its simplest form (Fig. 3) an electric telephone consists of a thin metallic disc; close behind this is a magnet; round the magnet is wound fine insulated wire; the ends of this wire are connected to the ends of the two 'line' wires passing to the other 'station'; there the other ends of the line wires are connected with a similar telephone. The mode in which this apparatus works is as follows: To one telephone the speaker's mouth is brought;

to the telephone at the other end the ear of the receiver of the message is applied. The voice causes the metallic membrane to vibrate; this induces electric currents in the bar magnet close to it; these, in their turn, cause electric currents in the coil of wire round the magnet; these currents pass along the line wire to the other station; here they pass through the coil of wire in that telephone, inducing currents in the bar magnet, and by these the metallic disc is caused to vibrate. The movements of one disc are so exactly reproduced in

FIG. 3.—ELECTRIC TELEPHONE.

Electric telephone; the magnet is shown black; the thin diaphragm is seen in section beneath the mouthpiece.

the other that not only the words, but also the voice, of the speaker can be recognised.

In practice it is more convenient to have at each station two instruments—one to speak into (the transmitter), and one to listen to (the receiver). It is also often better that the transmitter should be, not a telephone as here described, but a microphone, which magnifies the sound. In a microphone the place of the bar magnet with its coil of wire is taken by a collection of granules of carbon. The current from a small battery is made to pass through the carbon and also along the line wires to the other station and back.

The microphone acts thus: speaking against the metallic disc causes changes in the contact between the granules, and this causes changes in the amount of electricity passing from the battery through the granules and along the line wire. One reason why a

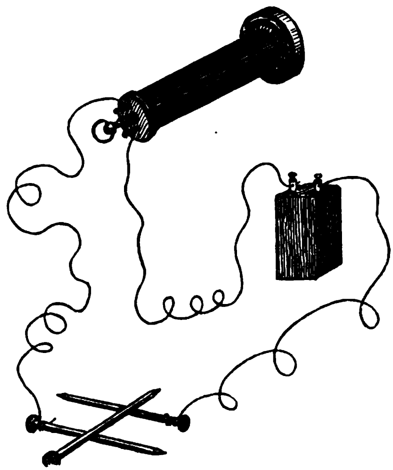


FIG. 4.—MICROPHONE.

The figure shows an early form of microphone. Instead of carbon granules, three long nails are used, arranged as shown. The vibrations of a sound near the nails alter the unstable contacts between the cross nail and the other two, and therefore the amount of electricity flowing from the battery (shown to the right) through the nails to the telephone (shown above). The telephone may be at a considerable distance from the nails (microphone), and therefore from the sound arising near the microphone.

microphone acts better as a transmitter than a simple telephone is because the amount of electricity sent through the circuit from even a small battery is greater than that induced by the magnet in the coil of wire.

As we shall have occasion later to refer to the phonograph, it will be well to describe it here.

It consists (Fig. 5) primarily of a diaphragm to be spoken against similar to the disc of a telephone. To the back of the diaphragm is attached a cutting-point;

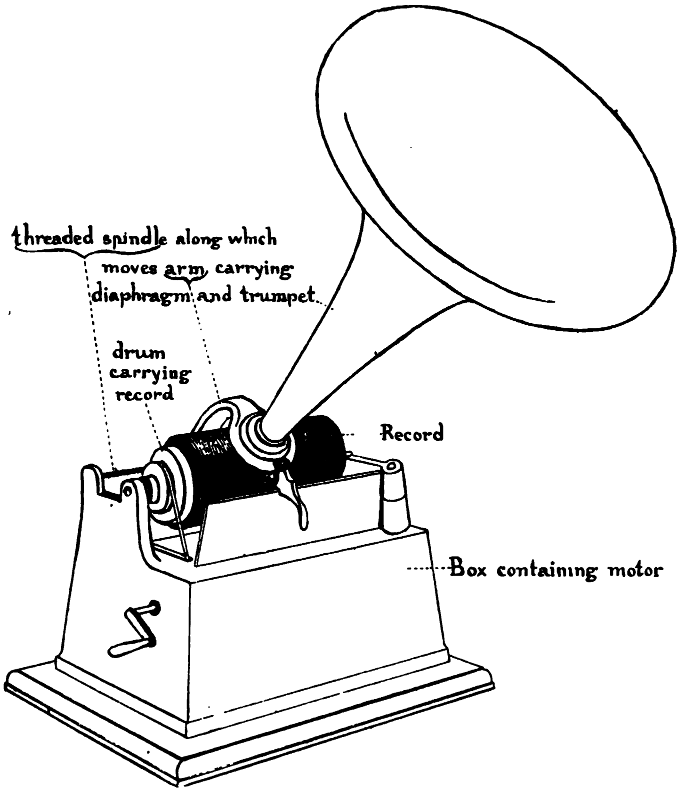


FIG. 5.—PHONOGRAPH.

beneath this point is arranged a cylinder of wax, 6⅞ inches in circumference; the cylinder is made to revolve by clockwork about twice per second, and at the same time the diaphragm, with its cutting-

point in contact with the cylinder, is made to travel lengthways of the cylinder ; it results that the point cuts a furrow of uniform depth spirally round the cylinder. If the diaphragm is spoken against, it and the cutting-point vibrate in and out and the furrow becomes of varying depths, and in this way there is engraved on the cylinder a record of the voice (Fig. 6). If now for the diaphragm with the cutting-point is substituted one with a blunt point, and the machine started from the beginning of the cylinder again, the blunt point and the diaphragm attached to it will follow the irregularities in the furrow on the record,

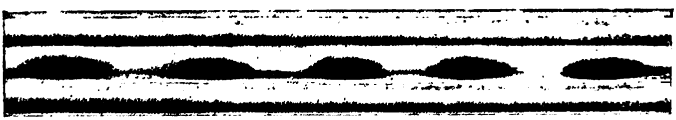


FIG. 6.—CYLINDRICAL RECORD (MAGNIFIED).

Greatly magnified portion of three grooves on cylindrical record ; the middle groove shows the indentations produced by a musical note.

and thus will be reproduced through a trumpet over the diaphragm the sounds of the spoken voice.

There is another kind of talking machine in which the record is in the form of a disc. Here the diaphragm which receives the voice is placed vertically, and has attached to its centre a vertical needle whose point traces the vibrations on a flat disc revolving horizontally beneath it. In order that the line on the disc shall be spiral, it is necessary that the diaphragm, with the needle attached, be made to move gradually towards the centre of the disc (Fig. 7).

Sound can be reflected from an object in the same

way that light can. The reflection of sound can be shown by a simple experiment: Take two cardboard tubes about 2 feet long and 2 inches wide—the tubes sold by stationers for sending music through the post will answer the purpose well—place the tubes at right angles, their ends nearly touching. At the far end of one tube place a watch (Fig. 8), and listen for the

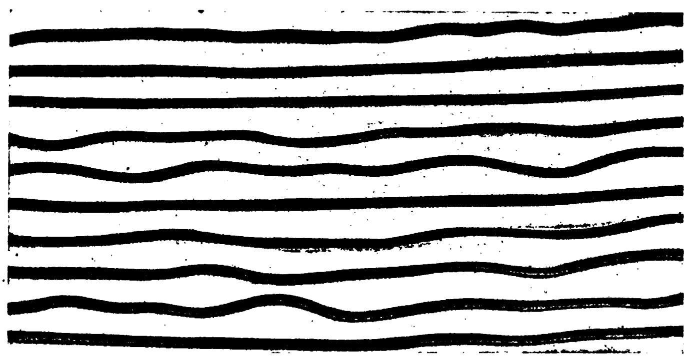


FIG. 7.—DISC RECORD (MAGNIFIED).

Part of flat disc record highly magnified; ten lines of spiral are shown. It would not be possible to read these records, for speech is carried on at the rate of a hundred or so words a minute, and at a pitch of several hundred vibrations a second; there would thus be an enormous number of vibrations in even a short sentence.

ticking at the far end of the other tube; probably it cannot be heard. If it can, wrap the watch up in a handkerchief so that it just cannot be heard, then place a book obliquely across the two near ends of the tube, and it will be possible easily to hear the watch. The sound passes down one tube, strikes the book obliquely, is reflected at the same angle, and passes down the other tube; but it is not necessary to use two

tubes to show the reflection of sound: the fact, which may readily be made sure of, that sound passes better along a tube than in the open is itself evidence, for it is due to the reflection of the sound from the walls of the tube back into the tube instead of allowing them to pass in other directions than that of the listener (see Fig. 9).

Echoes are due to the reflection of sound; multiple echoes to reflection from more than one surface.

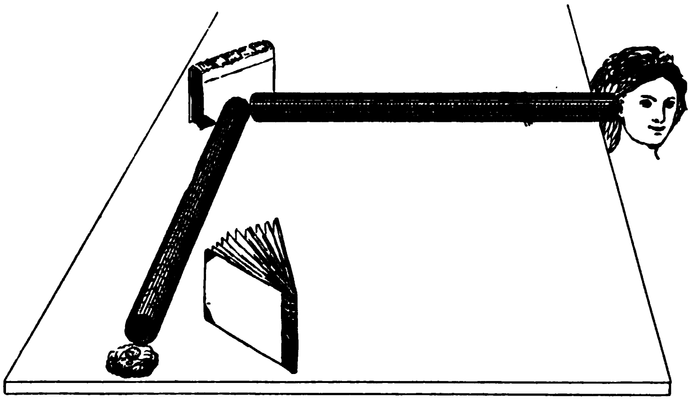


FIG. 8.—REFLECTION OF SOUND.
To show reflection of sound.

Sound can not only be reflected, it can also be refracted—that is to say, turned from its straight course in the same way that light is by a lens; but a glass lens will not act thus with sound: it stops the sound. It is necessary to use a lens consisting of a collodion envelope, and containing a gas heavier or lighter than air—say, carbonic acid.

Sound can also be diffracted from its course at the edge of an obstacle. If a watch is held 2 or 3 feet

from the ear, and a card placed between it and the ear, the ticking of the watch will seem to be of a lower pitch. What has happened is that the longer waves (the waves of lower pitch) have been diffracted from their course, and, turning somewhat in at the edge of the card, have reached the ear, while the shorter waves (of higher pitch) have passed nearly straight on and not reached the ear.

Before passing from the transmission of sound, it will be well to refer to the effects of heat, of cold, and of wind. It is a matter of common observation that sound travels exceptionally well on a clear, frosty

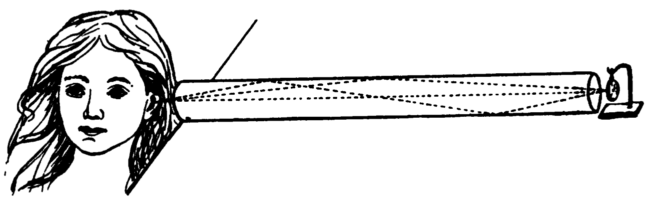


FIG. 9.—SOUND PASSING ALONG TUBE.
To show reflection of sound within a tube.

morning, and also on the evening of a warm summer day, especially on the surface of smooth water. Sound is also, as we all know, better heard down wind than against the wind. The explanation of these facts is as follows: The front of a wave of sound under uniform conditions may be considered to advance as a vertical wall. On a cold frosty morning the air near the ground is colder than that above it (that, in fact, is why the frost forms). Now, sound travels slower in cold than in warmer air, consequently the upper part of the advancing wave is ahead of the lower part, and the front of the wave leans down and therefore towards

anyone on the surface of the ground, who, in consequence, receives more sound than he otherwise would.

Similarly, on a hot summer's evening the earth cools rapidly, and the layers of air near the ground are colder than those higher up (this is why a ground-mist so often forms); here, too, the sound travels slower near the ground than higher up, and the same happens as on a frosty morning. The same, too, happens to leeward when a wind is blowing; the upper layers of air travel faster than the lower, which are impeded by trees, houses, and other obstacles, consequently the front of the wave leans down over anyone on the ground. In the opposite case, of being to windward of the source of sound, the front of the wave will lean back and look upwards, and the sound will be disposed to leave the ground altogether; the sound is not destroyed, but is lifted up, and could be better heard by anyone in a tower.

CHAPTER II

WAVES OF SOUND

SOUND-WAVES: HOW TO DRAW THEM AND HOW TO COUNT THEM — TWO WAVES AT ONCE: INTERFERENCE AND BEATS

IF a pebble be thrown into a pond, waves spread from where it falls to the bank; if a leaf be floating on the water, it will rise and fall with the waves, but otherwise remain pretty much where it was. The waves travel to the bank, but the particles of water stay about where they were, just as when waves of air pass over a cornfield; it is, as we know, only the waves which travel, the ears of corn moving only a few inches.

These are waves of crests and hollows on the surface of the water, but the air-waves which convey sound are in the depths of the sea of air in which we live. They are waves of alternate crowding and scattering of the particles of air, waves of compression and extension (Figs. 1 and 10). How these varying pressures are exactly distributed we will now try to make out.

If a vibrating tuning-fork be brought to the end of a tube, the waves of sound will be conveyed down the tube (Fig. 10). Let us start from the time when

the prong nearer to the tube is at its extreme right-hand position; it will then swing to the left at first slowly, then faster and faster, till it reaches the middle of its course, and finally slow down again until it arrives at its limit, where it will momentarily stop before returning. As the prong does this it will produce in the air in the tube nearest to it, firstly, a slight suction and extension, then, as it travels faster, a greater suction and finally less suction again. Similarly, when the prong returns from left to right, it will cause first slight compression, then more, and finally less compression again. These various alterations of pressure will travel down the tube, and at the completion of one double journey of the prong there will be in the tube the variations of pressure shown by the dots in Fig. 10. Passing from right to left, we get the following changes—normal, extension, normal, compression, normal. This is one whole wave or vibration; half a wave, a crest or a hollow, is sometimes called an oscillation.

The wave of sound will travel down the tube at the rate sound travels at—that is to say, about 1,090 feet a second. How many waves there will be in the 1,090 feet will depend on how often the fork vibrates in a second. If it is a C fork of frequency 256, the length of each wave will be $1{,}090 \div 256$ feet $= 4 \cdot 1$ feet; but, as we have said, the particles of air themselves do not travel that distance, or anything like it.

The varying pressures of the wave of sound in the tube are represented in Fig. 10 by the crowding and scattering of the dots, but it is easier to draw, and easier to think about, a wave if it is shown in crests and hollows by a curved line. Now, the tuning-fork

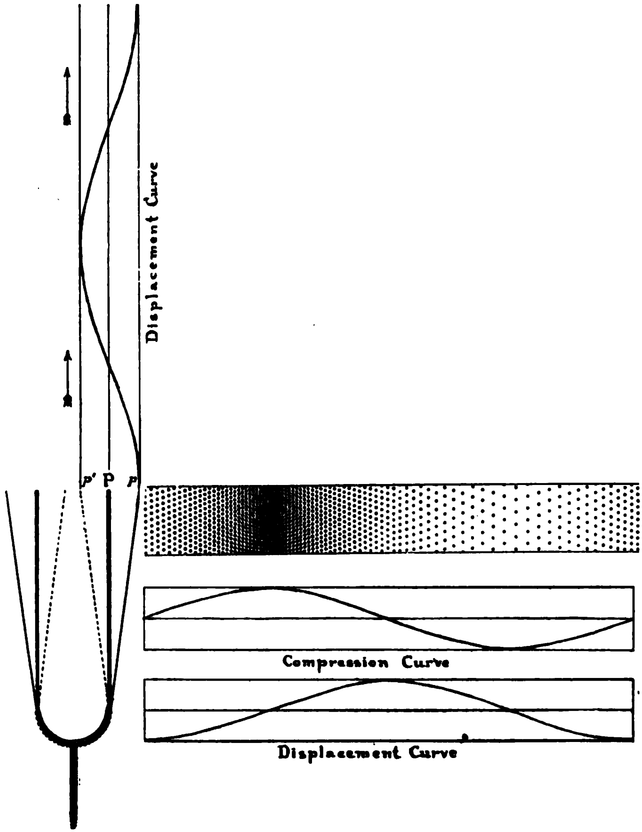


FIG. 10.—TUNING-FORK WITH WAVE OF SOUND.

Tuning-fork with wave of sound to its right. The relative crowding and scattering of the particles of air are shown by the arrangement of the dots; beneath them is shown the corresponding pressure curve. Above the prong P is shown a curve as would be drawn by a pencil attached to the prong on a strip of paper moving upwards in the direction of the arrow. For purposes of comparison this curve is drawn again below the pressure curve.

can itself be made to draw such a curve. If a pencil be attached to one of the prongs of the fork, and a strip of paper made to pass beneath the pencil, a curve will be drawn on the paper (Fig. 11), but to get a correct curve it is necessary to drive the paper by clockwork, in order that it may travel at a uniform rate. There is a much easier way of drawing these curves, but before describing it there are one or two points that must be considered.

It is clear that the prong of a tuning-fork moves somewhat, if not exactly, like the pendulum of a clock.

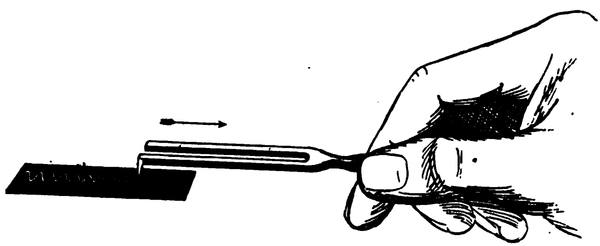


FIG. 11.—TUNING-FORK DRAWING CURVE.

The tuning-fork is being drawn to the right. Note that the waves remain the same length while the height is getting less.

They both go fastest in the middle of their course, and both momentarily stop at each end before going back; but as a tuning-fork goes by the 'spring' in the steel of which it is made, and a pendulum is driven by gravity, it is not clear that throughout their courses the two would travel at similar rates; still, as a matter of fact, they do, nor need we be surprised at this if we remember that in some cases a spring and in others a pendulum is used in clocks. A tuning-fork, in fact, is like two pendula fastened together; the prongs do

not swing parallel; they approach the centre and swing apart at the same time, like two sentries on duty at a gateway. Since a tuning-fork moves like a pendulum, only faster, if we can draw the curve of a pendulum, it will do for a tuning-fork.

A pendulum is a weight suspended by a rod or string. If such a weight be set swinging to and fro, the swings will gradually become shorter and shorter until they cease altogether. Now, as the swings become shorter they take almost exactly the same time; they do not take less time because they are shorter, nor more time because the pendulum is travelling slower; they take the same time. This important fact is said to have been discovered by Galileo. When a lad, he watched in the cathedral at Pisa the swinging of a lamp which had been drawn aside to be lighted; he thought that the swings took equal times; he had no watch, for watches had not then been invented, but he timed the swings by the pulse at his wrist, and found that he was right. The time a pendulum takes over a swing depends on its length. A pendulum 39·1 inches long takes one second over the double swing, the vibration that is; a pendulum four times that length takes two seconds, one a quarter the length half a second, and so forth.

Further, it does not matter whether the pendulum is made to swing to and fro, as it does in most clocks, or round in a circle, as it does in clocks with conical pendula (Fig. 12). If a weight suspended by a string 39·1 inches long be set travelling in a circle below the point of support, it will take one second to go round the circle, and as it dies down and the circles become smaller and smaller each will still take one second.

Let the course of such a pendulum be represented by a circle (Fig. 13). If the bob is looked at by an eye a long distance to the left of and on a level with it, the bob will appear to move in a straight line to and fro between XII. and VI.; further, as the bob takes equal times to travel between XII. and I., I. and II., and so on, it will appear to take equal times to travel

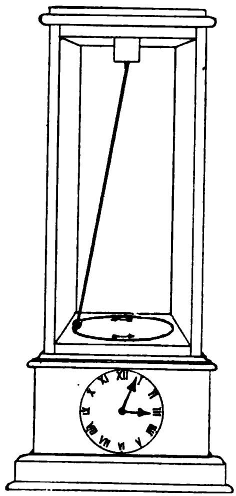


FIG. 12.—CLOCK WITH CONICAL PENDULUM.
Clock with conical pendulum which goes round in a circle.

between XII. and I′., I′. and II′., and so on the direct line XII. to VI., although these distances are very unequal.

Again, if instead of a conical pendulum going round the circle, there was a vertical pendulum swing to and fro just over the line XII. to VI., the time when the bob of the vertical pendulum would be over any point (say IV′.) would very nearly be the time when the

bob of the conical pendulum would appear to be at that point when viewed from the left.

We have to make a diagram which will show the movement of the prong of a tuning-fork—that is to say, the position it occupies at different times in one vibration. As the movement of a tuning-fork is the same as that of a vertical pendulum, a diagram which would show this would serve ; further, as the movement of a vertical pendulum is the same as the apparent movement of a conical pendulum along the straight

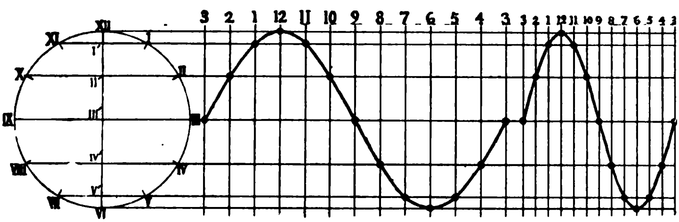


FIG. 13.—DRAWING OF PENDULAR CURVE.

For description, see text. The vertical lines, 3, 4, 5, etc., have marked on them the level at which the bob of the pendulum is at, at corresponding times. In the right-hand drawing these lines are only half the distance apart ; therefore there would be twice as many waves in the same length—*i.e.*, in the same time.

line XII. to VI., when viewed from one side, a diagram showing this would do for a tuning-fork.

The way to construct such a diagram is (see Fig. 13) : (1) Draw a circle for the course of the conical pendulum ; (2) to the right of this draw vertical lines numbered 3, 4, 5, etc., from right to left (see middle part of figure)—these are to represent the successive times when the pendulum is at III., IV., V., etc., and we are to mark on each of them the position the pendulum appears to be in on the line XII. to VI. at the corre-

sponding time. Thus, suppose the pendulum to start at III., and to take one second to go round the whole circuit; it will take one-twelfth of a second to go from III. to IV., IV. to V., V. to VI., and so on. As these times are equal the time lines 3, 4, 5, etc., must be put equal distances apart. When the pendulum is at III. it will appear to be at III′., and this position must be marked on the line 3 by putting a dot on it at the point where a horizontal line from III′. crosses it. When the pendulum reaches IV. it will appear to be at IV′., and this position must be marked on the line 4 by a dot where the horizontal line from IV′. crosses it, and so on round the whole face of the clock. It will be noticed that although the vertical lines 3, 4, 5, etc., are equal distances apart, the horizontal lines from III′., IV′., V′., etc., are at very unequal distances. In this way a succession of dots is obtained on the lines 3, 4, 5, etc. By joining them we get a curve which represents the movements of a tuning-fork, and therefore also the pressures in the waves of air produced by it. That being so, we may use the curve in Fig. 13 in place of the series of dots in Fig. 10, and we have drawn this curve below the dots in Fig. 10. On comparing the two, it will be noticed that at the three places where the curve is at the mid-line, at the sea-level, so to speak, the dots show the pressure to be normal; where the curve is below the line the dots show extension, where above compression.

We have already seen that the prong of a tuning-fork can be made to draw its own curve (p. 18); it is shown as doing so in Fig. 10. The curve shows the displacement of the prong of the tuning-fork; it is therefore a displacement curve; it is the same kind

of curve as the pressure curve. If it be placed under the pressure curve, as is done in Fig. 10, it will be seen that the displacement curve is a quarter of a period in advance of the compression curve.

The right-hand end of these curves corresponds to the earliest part of the sound-wave, therefore they must be read from right to left. If we had put the tuning-fork on the right of the tube, the curves would read from left to right. As the upper and lower parts of these curves are the same, if it is wished to read a right to left curve from left to right, all that is necessary is to turn the book upside down.

There is another easy way of drawing these pendular curves. Take a toy bucket, and make a small hole in the bottom of it. Let a boy swing it from side to side ; it is then a pendulum. Also let the boy walk backwards at the same time. As a fine stream of water runs out on the sand it makes a curve, which is a pendular curve, and also the curve for a tuning-fork, and also the curve for any pure note like those tuning-forks give. (See frontispiece ; in that drawing the curve has, for simplicity's sake, not been shown in perspective.)

If it be wished to draw the curve for another pure note, all that is necessary is to know the frequency of that note, and to alter accordingly the distance apart of the vertical lines. Take, for instance, the octave ; it is known that the number or vibrations per second are exactly double. In order to shorten the waves so that double the number may take the same length, the vertical lines must be put only half the distance apart (Fig. 13). The same note may be louder or softer. To represent it louder draw the clock face

larger; the waves will then be higher, but of the same length. Similarly, to show the note softer make the clock face smaller; the waves will then be of less height, but still of the same length.

These curves have a real existence. If a pure note were sounded into a disc talking-machine, a curve like those drawn would be traced on the record, only very much smaller; similarly, if a curve were drawn as described, then much reduced in size, engraved on a disc record, and passed through a gramophone, the corresponding note would be produced (see Fig. 7, p. 11).

The next thing is to count the number of vibrations or waves in a given note per second, the frequency, that is, of the note. The first to do this was Mersenne (1636), and he did it in a very ingenious way. He knew that if two lengths of the same string were taken, one twice as long as the other, equally stretched and set vibrating, the shorter string would vibrate twice as fast as the longer. Accordingly, he took a string giving a certain note, and kept on doubling its length till it went so slowly that he could count the vibrations with the eye; he could then calculate the number of vibrations of the note he started with. The frequency of the note of a tuning-fork can be found by making the fork trace its curve on a strip of paper made to travel at a known rate (see Fig. 11, p. 18).

The method of counting vibrations which has found most favour is by use of the siren. In its simplest form (Fig. 14) a siren consists of two circular plates pierced with corresponding holes. These holes slant in opposite directions in the two discs; the upper disc is free to revolve. It results that when air is blown

through the lower disc the upper disc rotates, and as it does so the passage through the holes is constantly being opened and closed. For scientific purposes it is necessary to add a mechanism, like a cyclometer, to count the revolutions of the upper disc. If now, for instance, the discs have five openings in them, and the upper disc revolves 200 times a second, there would

FIG. 14.—SIREN WHISTLE, TO BE BLOWN BY THE MOUTH.

Both the discs are pierced by five holes, which slant, as shown in section, in opposite directions. When air is blown into the whistle from below, the upper disc is made to revolve in the same direction as the hands of a watch. As the disc revolves faster and faster, the waves of sound caused by the opening and closing of the holes become more and more frequent, and the pitch of the note produced higher and higher.

be produced a sound of 1,000 vibrations per second. To ascertain the pitch of any note, the siren has to be made to revolve so as to produce a note of the same pitch.

Another way of determining the frequency of notes is by counting the waves on the cylinder or disc of a

talking-machine (see Fig. 6). If the rate at which the record is driven is known, the frequency of the note given out can be calculated. When a phonograph is not wound up enough the record travels slower and slower, the vibrations become fewer and fewer, the notes become lower and lower, ending at last, as the machine comes to a standstill, in a deep groan.

One result of counting vibrations may here be given. The smoothest concord between two notes is called 'the octave'; it is found that the frequency of the higher or octave note is always double that of the lower note, whatever its pitch may be. Thus, if a note called middle C has 256 vibrations per second, its octave will have 512.

The pitch of notes is not absolutely fixed. In Handel's time, as shown by his tuning-fork, which still exists, middle C was 252 vibrations per second. Now in England it is generally 264, but military bands make it 271; in France it is 261. For scientific purposes it is taken as 256, because that number can be easily subdivided, being eight two's multiplied together. For singers it is better to have a low pitch in order not to strain the voice; for brass bands a higher pitch is better, as then the music sounds more brilliant.

The next point to consider is, what happens when there are two sounds at once. Being able to draw the curves for pure notes, tones, as they are called, materially helps us to understand this. Take two notes of the same pitch, but one a little louder than the other, and draw their waves (Fig. 15). The compound wave that results is found by adding together at each point the two waves if they are on the same side

of the line, or by subtracting one from the other if they are on opposite sides ; this wave is shown by the thick line. We have in Fig. 15 made the two waves

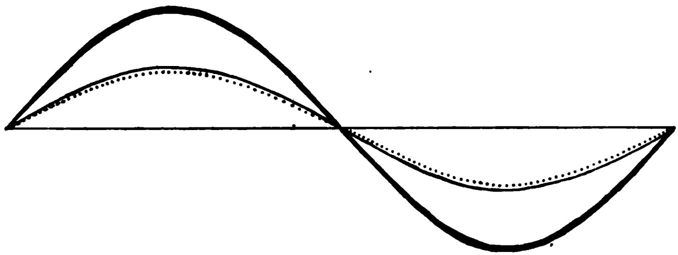


FIG. 15.—TWO WAVES IN SAME PHASE.

The thin line and the dotted line show two pure tones of the same pitch and nearly the same loudness ; the thick line shows the note that results from them. The two waves start together in the same direction—are in the same phase.

start together, but they need not do so. If they start exactly opposite, in opposite phase (Fig. 16), it will be seen that on adding them together the resultant is

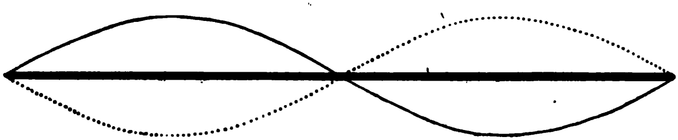


FIG. 16.—TWO WAVES IN OPPOSITE PHASE.

Two similar tones in opposite phase. The thick line represents the resultant note. There is no wave, and therefore no sound.

simply a straight line ; there is no wave, and no sound at all. It certainly seems strange that two sounds should so neutralize one another as to produce no sound whatever, but that such a thing is possible may

be seen with an ordinary tuning-fork. Strike it, hold it to the ear, and turn it slowly round; the sound is heard to rise and fall. When the fork is obliquely to the ear very little sound is heard; the reason is that

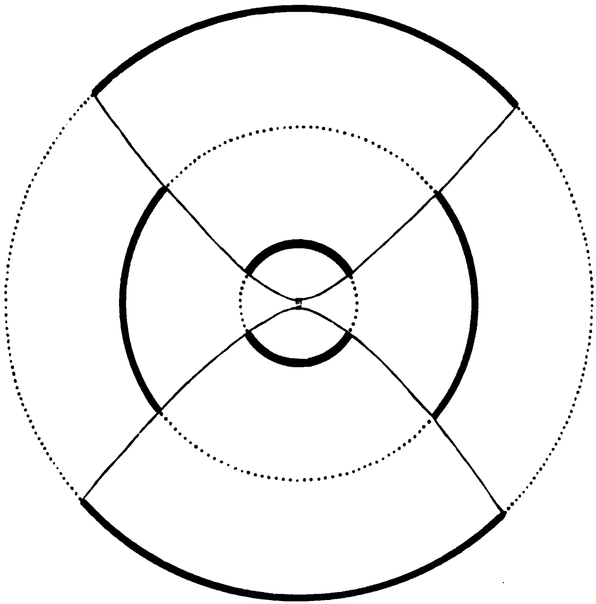


FIG. 17.—WAVES FROM TUNING-FORK.

To show sound-waves from tuning-fork; the two prongs are seen from above in the centre. The thick lines show compression part of sound-wave, the dotted rarefaction; along the four curved lines the opposite waves meet and produce much less sound.

two sounds are interfering with one another—hence this phenomenon is called interference. The way a tuning-fork acts is that the prongs approach and swing apart at the same time; the result is that while the compression part of a wave is being sent out from

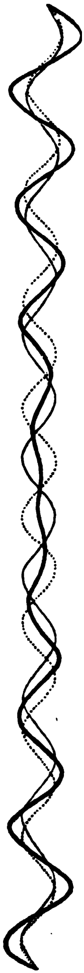


FIG. 18.—RESULTANT OF TWO WAVES.

Two tones are presented—one by a thin continuous line, one by a dotted line. The note resulting from the two tones is shown by the thick line. There are eight waves of the first tone to nine of the other tone, therefore the tones are in the ratio of 9 : 8—that is to say, of a major tone. The thick line shows large waves (a loud sound) at the two ends, and small waves (a small sound or lull) at the middle. If the length drawn corresponded to one-hundredth of a second, there would be 800 and 900 vibrations per second in the two tones, and 100 lulls of sound per second, and 100 beats. Thus the frequency in the beats is the difference between the frequencies of the tones ($900 - 800 = 100$).

between the prongs the extension part of a wave is being sent out from the outer aspects of the prongs. In the oblique positions these waves meet and interfere with one another (see Fig. 17).

Interference can also occur between two tones not of the same pitch. Take a note of 800 vibrations to the second, and draw eight of its waves corresponding to a one-hundredth of a second; take another tone of frequency, 900, and draw nine of its vibrations on the same mid-line (Fig. 18). By adding and subtracting we get the resultant curve shown by the thick line; it will be seen that at its centre the waves die down; there is a calm where there would be next to no sound. At the two ends of the length drawn the waves of the resultant are higher than either of the original waves; here the sound would be louder than elsewhere. The portion drawn corresponds to the one-hundredth of a

second. If the drawing were prolonged to the right it would merely be a repetition of itself; hence we see that in a whole second there would be one hundred of these rises of sound—beats, as they are called. As the frequency of the tones was 800 and 900, their difference was 100, which is the number of the frequency of the beats, and generally it will be seen that with two notes the difference of their frequencies is the frequency of the beats. If the notes are 800 and 801 vibrations per second, the beats will be one per second.

When beats are not too frequent it is quite easy to hear them. If two similar tuning-forks are sounded together, they should give a smooth, continuous note. Bind a little cotton-thread round one prong of one of the forks; this will make it go slower, slightly lowering its pitch. If now both forks are struck and held to the same ear a marked rise and fall in the sound will be heard; the forks beat. Sometimes two of the same forks beat when sounded together; this is simply because they are not exactly in tune—in fact, beating is a very delicate test of pitch, and therefore very useful in tuning. Since the number of beats per second is the difference between the frequencies of the notes, the object in tuning is to make the beats as few as possible. When there are only two beats per second the difference between the notes is only two vibrations per second, and the notes are in tune.

If the beats are very frequent they are not noticed; also, if they are infrequent, as the rise and fall is gradual they then too are not noticed; but at moderate rates they are quite evident, causing a roughness in the sound—in fact, they resemble the flickering of a flame, and, like it, are annoying. These beats are extremely

important, for, as we shall see later on, they are the cause of all discord in music. If the beats are fewer than ten or more than seventy per second, they do not produce much effect; but between these limits they produce discord, the greatest discord being with about thirty beats a second.

But beats are sometimes of use in music; the wavy effect of the Voix Céleste stop on the organ is obtained by sounding a pair of pipes so tuned as to give about three beats a second.

The thick curved lines in the figures showing the resultant curves are important, for they show the curve which is drawn on the disc of a talking-machine when the various notes are played together, also the movement which takes place in the drums of our ears (Fig. 7, p. 11).

CHAPTER III

MUSICAL SCALES

MAJOR SCALE—MARKING OF NOTES—INTERVALS—FLATS AND SHARPS — VIBRATION OF STRINGS — OVERTONES—CONCORD AND DISCORD—THE SEVEN CONCORDS—COMBINATION TONES—ORIGIN OF MAJOR SCALE—EQUAL TEMPERAMENT—TRUE INTERVALS—MINOR SCALE—PENTATONIC SCALES.

THE human ear, being very delicate, can distinguish an immense number of different notes, but for the pleasure of music it is necessary that the sounds should be separated by distinct intervals, and not glide into one another, as in the sighing of the wind. There must, therefore, be a selection of notes made—a musical scale, in fact.

Further, it must be pointed out that modern music depends on a keynote, to which all the other notes are related, from which they proceed, and to which they return.

To construct such a scale, the octave has been divided into seven notes, which are named after the first seven letters of the alphabet ; this scale is called the major scale.

The relative frequencies of the notes in the major scale are as follow, starting from C as the keynote :

	C	D	E	F	G	A	B	C^1
	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
	Keynote.	Second.	Third.	Fourth.	Fifth.	Sixth.	Seventh.	Octave.
Sol-fa Scale	doh	ray	me	fah	sol	lah	te	doh^1
	d	**r**	**m**	**f**	**s**	**l**	**t**	**d^1**

Thus, if C is 256 vibrations per second, G will be $256 \times \frac{3}{2} = 384$ vibrations; and B $256 \times \frac{15}{8} = 480$ vibrations.

To distinguish the notes of different octaves, those of the middle octave are left unmarked, those of the octave above are marked with a 1 above, those of the octave below with a 1 below. Thus, we get for the C's of seven octaves, C_3, C_2, C_1, C, C^1, C^2, C^3. Music seldom extends much beyond seven octaves—three above and three below the middle octave. Higher notes are too shrill to be pleasurable, and lower notes are barely audible.

How the ratios in the major scale were arrived at will be considered later, but it may here be pointed out that the steps or intervals are not equal. The interval between two notes in music is a matter of proportion, and is found therefore by dividing the frequency of the higher note by that of the lower. Similarly, the sum of two intervals is obtained by multiplying (not adding) together the two intervals. Thus, if we have three notes $C = 256$, $G = 384$, and $C^1 = 512$. The interval between C and G is $384 \div 256 = \frac{3}{2}$, and the interval between G and C^1 is $512 \div 384 = \frac{4}{3}$; the total interval between C and C^1 can be obtained directly, $512 \div 256 = 2$, or by multiplying together (not adding) the two intervals C to G and G to C^1, thus—$\frac{3}{2} \times \frac{4}{3} = 2$.

If the intervals in the major scale are worked out in this way, they will be found to be :

C to D	D to E	E to F	F to G	G to A	A to B	B to C
$\frac{9}{8}$	$\frac{10}{9}$	$\frac{16}{15}$	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{9}{8}$	$\frac{16}{15}$

It will be seen that there are no less than three different intervals in the scale—$\frac{9}{8}$, called a major tone; $\frac{10}{9}$, a minor tone; and $\frac{16}{15}$, a semitone.

In music it is often wished to change the keynote, or to play the same melody starting on a different note; but, as the intervals in the major scale are not equal, we cannot start on any note, and find the other notes merely by counting up or down from our new keynote. An example will make this clear. We will take the simplest fraction in the scale—this is, $\frac{3}{2}$, the fifth note (G). If now we take this, instead of C, as keynote, the interval between it and the next note above, its second, which is A, is $\frac{10}{9}$, whereas the interval between C and its second (D) is $\frac{9}{8}$. This difference, though not much, is quite perceptible, but we will let it pass. It will be found that the intervals between G and its third, fourth, fifth, sixth, and eighth (octave) are the same as between C and its corresponding notes, but the interval between G and its seventh, and between C and its seventh, do not correspond.

The interval between C and its seventh (B) is $\frac{15}{8}$; to correspond with this the seventh of G $\left(=\frac{3}{2}\right)$ should

be $\frac{3}{2} \times \frac{15}{8} = \frac{45}{16}$; but the seventh note starting with G is F^1, which is $\frac{4}{3} \times 2 = \frac{8}{3}$.

These are not nearly the same, for

$$\frac{45}{16} = \frac{135}{48}, \text{ and } \frac{8}{3} = \frac{128}{48};$$

therefore F^1 will not do for the seventh of G, but we require a new note standing to F^1 in the proportion of 135 to 128; in other words, F must be sharpened by the interval $\frac{135}{128}$. This new note is made and called F sharp, and written Fe or F♯. If F sharp is substituted for F, we get the major scale of G.

If, instead of taking for the new keynote the fifth above C, we take the fifth below its octave C^1 (*i.e.*, F), we shall find that what should be the fourth of F does not correspond with the fourth note starting from F—*i.e.*, B; thus the fourth of $C = \frac{4}{3}$, and therefore the fourth of F $\left(= \frac{4}{3}\right)$ should be $\frac{4}{3} \times \frac{4}{3} = \frac{16}{9}$, but the fourth note starting with F is B $\left(= \frac{15}{8}\right)$. These are not nearly the same, for $\frac{16}{9} = \frac{128}{72}$, and $\frac{15}{8} = \frac{135}{72}$.

Therefore, for the fourth of F we require a note lower than B in the proportion of 128 to 135. In other words, B must be flattened by the interval $\frac{128}{135}$. This new note is made and called B flat, and written Ba or B♭. If it is substituted for B, we have the major scale of F.

By starting from the scale of G, and taking its fifth note D as keynote, we shall find that again the seventh (now C) requires to be sharpened to the same extent as F. If this is done we have the scale of D, in which there are two sharps—namely, F♯ and C♯. Similarly, by proceeding upwards, always by fifths, we get the scales for A, E, and B, finding in each case that the seventh (which is G, D, and A respectively) requires to be sharpened; the result is that in the scale of B major there are five sharps—namely, F♯, C♯, G♯, D♯, A♯. If these sharp notes were substituted for the major notes, it would be possible to play in the key of B major, but not in any other major scale. To play in all keys it is necessary to have the major notes and also their sharps and flats; therefore these have been added, and thus there are in written music twenty-one notes in the octave.

We will now proceed to consider how the major scale arose. If a string is pulled taut, then plucked aside and let go, it will vibrate backwards and forwards and produce a musical note. What note that will be will depend mainly on three things: (1) The length, (2) the thickness, (3) the tension of the string; the shorter, the thinner, the tauter the string, the higher will be the note it gives.

The string will vibrate from side to side if allowed to vibrate as a whole (Fig. 19, *a*); if held in the middle, it will vibrate in two halves (Fig. 19, *b*); if held at one-third of its length, it will vibrate in three equal parts (Fig. 19, *c*)—that is to say, not only the point where it is held stays still, but also that other point where it divides into thirds. That this is so can be seen by making little paper riders like an inverted V

and placing them on the string ; that at the third will stay on, while those elsewhere will jump off, when the

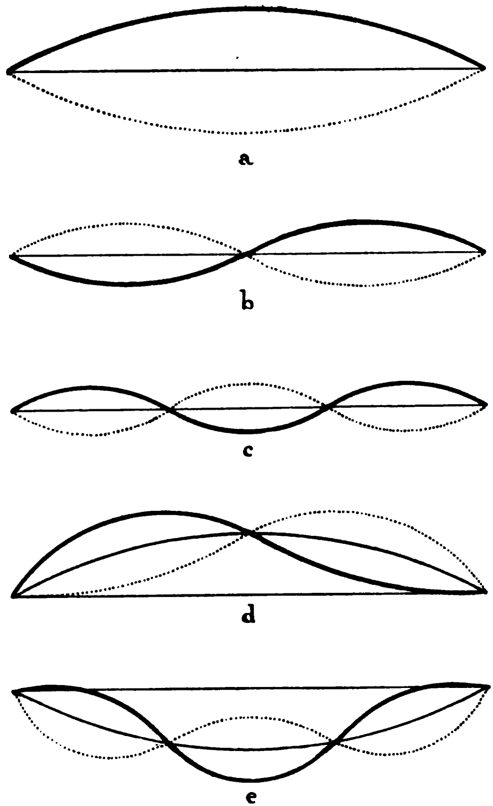


FIG. 19.—VIBRATIONS OF A STRING.

To show the vibrations of a string. (*a*) The string is vibrating as a whole above thin continuous line, below dotted line. (*b*) The string is vibrating in two halves. (*c*) The string is vibrating in thirds. (*d*) The string is vibrating as a whole, thin continuous line and also in halves, thick continuous and dotted lines. (*e*) The string is vibrating as a whole, thin continuous lines and in thirds, thick continuous and dotted lines.

string vibrates. Similarly, if the string is held at one-quarter of its length, the riders at the half and three-quarter points will stay on; those elsewhere will jump off. The stationary points are called nodes, the moving parts between the nodes loops (Fig. 20).

Now, even if the string is not held at the half, third, and quarter points, it can, and often does, at the same

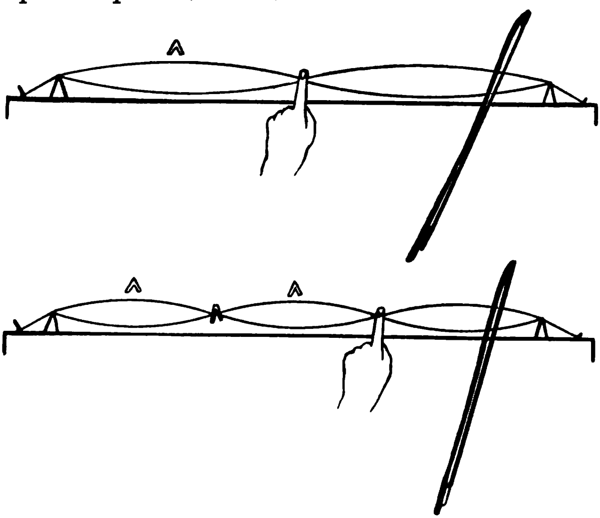


FIG. 20.—RIDERS ON VIBRATING STRINGS.

Shows riders jumping off at the loops and remaining on at a node.

time that it vibrates as a whole, vibrate also in these simple fractions. That this is possible can be seen from Fig. 21.

If the string does this, it produces not only the note caused by it vibrating as a whole, but also the notes produced by strings a half, a third, a quarter, and so forth of its length—that is to say, notes of twice, three

times, and four times its frequency, and so on. These notes, which go to make up the whole compound note, are called tones or overtones. The first has the same frequency as the prime note, and is therefore not literally an *over*tone; the second, twice that frequency; the third, three times, and so on.

These tones are also called harmonics; but the name is not a very good one, because, although they all harmonize with the prime tone, the higher overtones do not harmonize with one another.

If we take the note C, frequency 128, the frequency

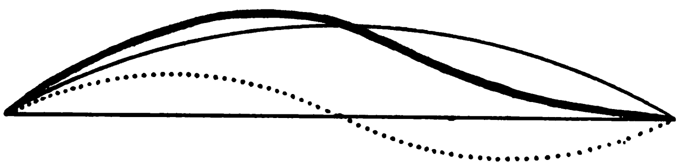


FIG. 21.—COMPOUND VIBRATION OF STRING.

The string is endeavouring to vibrate as a whole (thin continuous line) and also in halves (dotted line). No part of the string can, it is true, be in two places at the same time, but the result of the attempt is that the string would occupy a position indicated by the thick line.

of the first six overtones will be 128, 256, 384, 512, 640, 768. By comparing these numbers with the ratio of the major scale (p. 33), it will be seen that the overtones making up the note C_{I} are C_{I}, C, G, C^{I}, E^{I}, G^{I}, etc.

The overtones are not necessarily all present, and when present may vary in their loudness. It is by the difference in the overtones that we are able to distinguish on what instrument a particular note is being played. On the pianoforte the makers endeavour to have in the middle and lower notes all the first six overtones present and fairly loud; indeed, in the

lower octaves the second and third overtones are often as loud as the first or prime tone. The presence of these overtones gives richness to the notes of an instrument ; pure notes (*i.e.*, tones) sound dull.

The best way to hear overtones is by the use of Helmholtz's resonators (Fig. 22). Each consists of a hollow metal sphere with two opposite openings ; the larger of these is to admit the sound, the smaller to fit into the ear. Each resonator according to its size resonates to some particular pure note or tone. If a resonator is held to the ear and a compound note

FIG. 22.—HELMHOLTZ'S RESONATOR.
For description, see text.

sounded the resonator will be heard distinctly responding if, and only if, its proper tone is one of the overtones making up the compound note. By the use of resonators of different sizes the various tones in a compound note can be separately picked out.

It is possible to satisfy one's self of the existence of overtones in the piano in the following way : press gently down, without sounding the note, the key of C^{1} (the upper C) ; now strike sharply the middle C and let the key fly back, still holding down upper C^{1}. This note will be heard sounding after middle C has died

away; it has been made to sound by the vibrations of the second overtone of middle C, which is the same note ($C^{\prime}$).

At the piano the reader will find that the note $C_{\prime}$ will go very well with C, well with $G_{\prime}$ and $F_{\prime}$, but badly with $D_{\prime}$ and $B_{\prime}$. That $C_{\prime}$ should go badly with $D_{\prime}$ is in accord with what has been said about the frequency of beats (Chapter II.). If the frequency of $C_{\prime}$ is 128, that of $D_{\prime}$ will be $128 \times \frac{9}{8} = 144$; therefore the frequency of their beats is $144 - 128 = 16$. This comes within the limits that produce roughness (p. 31), but this does not explain why $B_{\prime}$ should be discordant with $C_{\prime}$, nor why C should be with $C_{\prime}$ a more perfect concord than is $G_{\prime}$. It is due to the overtones and the discords arising between them.

We have already seen that the earlier overtones of the note $C_{\prime}$ are $C_{\prime}$, C, G, $C^{\prime}$, $E^{\prime}$, $G^{\prime}$ (p. 39).

Similarly, the first three overtones of C will be C, $C^{\prime}$, and $G^{\prime}$. Therefore, if the notes $C_{\prime}$ and C be sounded together, no new tone will be introduced among the earlier and louder overtones. Consequently, there are no beats and no roughness, and we understand why a note and its octave go so well together, and why it is even possible sometimes to mistake the octave for the note.

In the following table are represented the earlier overtones of a note $C_{\prime}$, together with those of its octave C, its fifth $G_{\prime}$, its fourth $F_{\prime}$, major third $E_{\prime}$, major sixth $A_{\prime}$, minor third Ea, and minor sixth Aa.

Note and	C_1		C		G		C^1		E^1		G^1	
Octave			C				C^1				G^1	
Note and	C_1		C		G		C^1		E^1		G^1	
Fifth		G_1			G			D^1			G^1	
Note and	C_1		C		G		C^1		E^1		G^1	
Fourth		F_1		F			C^1			F^1		A^1
Note and	C_1		C		G		C^1		E^1		G^1	
Major third		E_1		E		B			E^1		Ge^1	
Note and	C_1		C		G		C^1		E^1		G^1	
Major sixth		A_1		A					E^1			A^1
Note and	C_1		C		G		C^1		E^1		G^1	
Minor third		Ea_1		Ea		Ba		Ea^1			G^1	
Note and	C_1		C		G		C^1		E^1		G^1	
Minor sixth		Aa_1		Aa				Ea				Aa^1

Represented in the staff notation the results stand as follows (see p. 43):

Bearing in mind that a tone and semitone are discordant, we see how concordant are the intervals of an octave, fifth, fourth, major third, and major sixth. The minor third and minor sixth are less concordant, and have only comparatively recently been allowed to pass for concords—indeed, they probably would not have been except for their relationship to the major sixth and major third respectively; still, they are now recognised as concords, and there are therefore in music seven concords, of which the ratios are as follows:

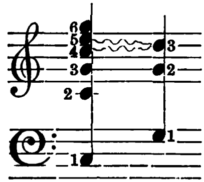
Octave	2 : 1
Fifth	3 : 2
Fourth	4 : 3
Major third	5 : 4
Major sixth	5 : 3
Minor third	6 : 5
Minor sixth	8 : 5

These seven are the only concords in music; all other ratios are discords.

OCTAVE.

No discord.

FIFTH.



Two discords, but with higher and less loud overtones.

FOURTH.

Third of lower tone discordant with second of higher note.

MAJOR THIRD.

Fourth overtone of lower discordant with third of upper note.

MAJOR SIXTH.

Third tone of lower discordant with second tone of higher note.

MINOR THIRD.

Fourth of lower dissonant with third of higher.

MINOR SIXTH.

Third of lower dissonant with second of upper.

Apart from beats between overtones, dissonance may arise between two pure notes (which have no overtones). If we take a pure tone C = 256, its minor third would be 327. This would give $327 - 256 = 71$ beats per second, which would be on the borderland between concord and discord (see p. 31); but dissonance may arise between two pure tones much further apart than a minor third. This is due to the occurrence of difference tones—a new tone produced by the combination of two tones sounded together. The frequency of the new tone is the difference of the frequencies of the two tones that produce it. If two tones, one of 500 vibrations per second and one of 400, be sounded, a new sound will be produced of 100 vibrations per second. A difference sound can be well heard from a double whistle; also when two flageolets are blown loudly. Difference tones are made use of in organ building; the note of an inconveniently long pipe can be obtained by using two shorter pipes of such length that their difference tone is the note required. Difference sounds cannot, as a rule, be heard any louder when a resonator is held to the ear, which shows that generally they have little or no existence in the external air, but are made in the ear itself. These difference tones were first described by Sorge, a German organist, in 1745.

We are now in a position to consider the origin of the major scale. On comparing the scale (p. 33) with the list of concords (p. 42), it will be seen that five of the seven notes are the same proportions as five of the concords; but it cannot be said that these notes were taken because they were concordant, for many of the intervals were fixed in the times when

music consisted mainly of a succession of single notes—of melodies, that is ; but even in melodies there has to be, to please the ear, some connection with the previous note—something in common between them—and this is very often that the new note is one of the overtones of the prior note, just as in a dance two successive movements have a connecting link in some step common to both.

This serves to explain five of the notes in the major scale—namely, the third, fourth, fifth, sixth, and octave. Both the other two—namely, the second D $\left(=\text{ray}=\frac{9}{8}\right)$ and the seventh B $\left(=\text{te}=\frac{15}{8}\right)$—are derived not directly from the keynote, but from its fifth. The fifth of the fifth is $\frac{3}{2}\times\frac{3}{2}=\frac{9}{4}$; this note is above and outside the octave, but it can be brought into it by taking it an octave lower, thus $\frac{9}{4}\div 2=\frac{9}{8}=\text{D}=\text{ray}$. The seventh is the third of the fifth, $\frac{3}{2}\times\frac{5}{4}=\frac{15}{8}=\text{B}=\text{te}$.

We have seen that in order to allow of a melody being transposed from one key to another, sharps and flats have been added to the musical scale. Many of these notes fall very near to one another, and on keyed instruments, which have to be tuned beforehand, one key may be made to do duty for two notes. Thus in the piano the twenty-one notes in an octave are reduced to twelve. But with the twelve notes it was not possible to transpose accurately from any key to any other ; what was right for one was wrong for another. After much consideration, it was decided to make the intervals between the twelve notes in the

octave equal ; this interval had to be the number which when multiplied by itself twelve times comes to two—the twelfth root of two, which is 1·05946.

This arrangement is called equal temperament. The result is that while the scale is never quite right for any key, it is equally and not very much wrong for all. The fifth G, instead of being, as it should be, 1·5, is 1·498, and the third E, instead of 1·25, becomes 1·2599.

This tempered tuning only applies to keyed instruments, such as the piano and organ. Instruments like the violin, in which the notes are made by ear at the time, are played by the performers in true intervals, unless accompanied by a piano. The same applies to the voice—in fact, singers should be careful not to sing too much with a piano or harmonium.

It so happens that seven octaves are very nearly equal to twelve fifths, for seven two's multiplied together = 128, and twelve $\frac{3}{2}$'s $\doteq$ 129·7. Ever since this was discovered, which was many centuries ago, musicians have been trying to make twelve fifths do duty for seven octaves. This is done in the chromatic scale, but if a violinist were to ascend by twelve fifths, and come down by seven octaves, he would be a little out from his keynote. If he were to do the same a second time, further out, and so on. The only way to keep quite right is to come down by the same intervals as are used in going up.

In the list of concords (p. 42) there are two, the minor third $\frac{6}{5}$, and the minor sixth $\frac{8}{5}$, which are not represented in the major scale. To explain their origin, it is necessary to point out that a note and its

octave so closely resemble one another that one is often exchanged for the other ; if this is done, the relation of two notes becomes inverted. Thus, if we take C and its sixth A, their interval is $\frac{5}{3}$; but if instead of C we take its octave C', then the interval becomes, by dividing the higher by the lower, $2 \div \frac{5}{3} = \frac{6}{5}$. This interval is, then, the inversion of the major sixth ; if put into the major scale it would come next below the major third, $\frac{5}{4}$, and is therefore called the minor third.

Similarly, the inversion of the major third $\frac{5}{4}$ is $\frac{8}{5}$, the minor sixth.

The minor third $\frac{6}{5}$ s not quite the same as E♭, which is $\frac{5}{4} \times \frac{128}{135} = \frac{160}{135}$, whereas $\frac{6}{5} = \frac{162}{135}$, but in the tempered scale of the piano E flat has to do duty for both.

Sometimes in music the minor third $\frac{6}{5}$ is substituted for the major third $\frac{5}{4}$; when this is done the major scale is altered into the minor.

Thus one form of the minor scale is—

$$1 : \frac{9}{8} : \frac{6}{5} : \frac{4}{3} : \frac{3}{2} : \frac{5}{3} : \frac{15}{8} : 2.$$

There are two other forms of the minor scale, but the important point common to all three is that the third is $\frac{6}{5}$—*i.e.*, minor.

There is a great difference between a major and minor key. This is due to the less perfect concord between the third and the keynote in the minor scale. In one variety of the scale of C minor the notes are exactly the same as those in the major scale of E flat, but the two are quite different in effect. The major scale of E flat is only the scale of C major played throughout at a different pitch; whereas the scale of C minor has the most important of all intervals, that of the third, altered. The difference between the major and minor mode is thus described by Helmholtz: 'The major mode is well suited for all frames of mind which are completely formed and clearly understood, for strong resolve, and for soft and gentle or even for sorrowing feelings, when the sorrow has passed into the condition of dreamy and yielding regret. But it is quite unsuited for indistinct, obscure, unformed frames of mind, or for the expression of the dismal, the dreary, the enigmatic, the mysterious, the rude, and whatever offends against artistic beauty, and it is precisely for these that we require the minor mode, with its veiled harmoniousness, its changeable scale, its ready modulation, and less intelligible basis of construction.'

Besides the major and minor scales of seven notes, there have been used in various countries scales of five notes. In one of these pentatonic scales many of the old Scotch songs were written. It closely resembles the major scale reduced to five notes by the omission of the fourth and seventh. The air of 'Ye Banks and Braes' is in the Sol-Fa Notation, as follows:

{ : s_1 | d : — : d | r : d : r | m : s : m | r : d : r || }
Ye banks and braes o' bon - nie Doon, How

{ || m : - .r : d | d : l_1 : s_1 | s_1 : l_1 : d | r : — :
can ye bloom sae fresh and fair !

Note that there is no fah and no te.

If this is taken in the key of F♯, the five notes, d, r, m, s, l, will be F♯, G♯, A♯, C♯, D♯. These notes are the black keys of the pianoforte, and thus it is seen that this pentatonic scale can be played on the black keys of the piano.

CHAPTER IV

ORGAN-PIPES

RESONANCE IN TUBES; ORGAN-PIPES.

IF a tuning-fork is brought to the mouth of a tube, the sound from the fork may or may not be increased by resonance from the tube. Whether it is increased or not depends mainly on two things—(1) the length of the tube compared with the length of the waves of sound from the fork, and (2) whether the far end of the tube is open or closed.

We have already seen how a sound-wave passes down a tube (Fig. 10, p. 17); if the end is closed, the wave is reflected on reaching it (Fig. 8, p. 12). Thus, on the compression part of the wave reaching the plug it is reflected, and travels back up the tube as a wave of compression; similarly, the rarefaction part travels back as rarefaction. If the end of the tube is open the reverse happens; the escape of the compression part of a wave causes a wave of rarefaction to travel up the tube, and, similarly, a wave of rarefaction is reflected as a wave of compression.

A wave of compression moving to the right will move or tend to move the particles before it to the right, and after reflection from a closed end will tend

to move them to the left. Similarly, a wave of rarefaction when moving to the right will draw the particles to the left; when moving to the left it will draw the particles to the right.

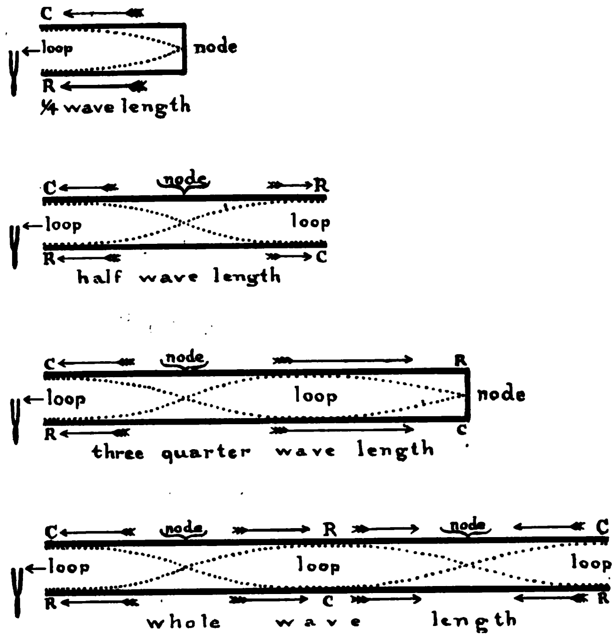


FIG. 23.—TUBES WHICH RESONATE WITH SAME WAVE.

All four tubes are drawn at the time when the right-hand prong of the tuning-fork is in its middle position, and moving rapidly to the left. The ingoing wave travelling down the tube is represented in the lower side of tube, and the returning wave on the upper side. The arrows represent the movements of the particles of air (not the direction the waves are travelling in). At the nodes there is no movement.

We will consider what will happen when a middle C tuning-fork is brought to the mouth of tubes of different lengths (Fig. 23). We have already seen

that the wave-length of middle C is about 4 feet (p. 16); the tubes drawn therefore will be 1, 2, 3, and 4 feet long. Let us ascertain first what is the state of the air at the mouth of the quarter wave (1 foot) tube when closed, and at the time the prong nearer it is in the middle of its course and travelling to the left: it will then be going at its fastest, and drawing the air particles to the left, causing a wave of rarefaction. This is indicated by the letter R and the arrow placed below the tube; but at the mouth of the tube there will also be that part of the previous wave which has passed down the tube, been reflected at the end, and has now reached the mouth. As the tube is a quarter-wave length that part will be that which entered half a period before, when the prong was also in the middle of its course, but moving to the right and causing compression. This compression, having been reflected, will now be causing the air to move to the left; this is indicated by the letter C and the arrow placed above the tube. It will be seen that the ingoing and the outcoming wave are both acting in the same direction and helping the fork, and thus the tube resonates with the fork.

Similarly with respect to the closed three-quarter wave-length tube (the 3-foot tube). The outcoming wave is the part which started a period and a half earlier, and is therefore the compression part reflected from the plug, and now moving the air particles to the left.

The half-wave and whole-wave length closed tubes are not figured; but it is easy to see that in them the ingoing and outgoing waves will not work together, and that therefore these tubes will not resonate with the fork.

With respect to open tubes, taking the half-wave length tube first, the outcoming wave will be that caused by the part of wave which entered a whole period before the rarefaction part of the ingoing wave; but on reaching the open end that wave will not have been simply reflected, but instead a wave of compression will have been sent up the tube, and it is this compression wave, moving the air to the left, which will be issuing from the tube mouth; it will act in the same way as the ingoing wave, and the tube will therefore resonate. Similarly, it will be seen that the whole wave-length open tube will resonate, and also that the quarter and three-quarter length open tubes will not resonate, and generally that an odd number of quarter-lengths will resonate if the tube is closed, and an even number of quarter-lengths if the tube is open.

The arrows in the lower figures show that the air in one part of the tube is moving in one direction, at another part in another, while at certain places, called nodes, it is being pulled or pushed in opposite directions at the same time, and consequently does not move. At the parts of the tubes marked loops, as the successive waves pass along the particles of air move first in one direction then in the other, the air pressure changing but little; while at the nodes the particles remain still, but undergo marked changes of pressure. The same happens when a string vibrates in parts (Fig. 19); the loops move first one way then the other, but the nodes stay still.

At the entrance and at an open end the particles of air are free to escape, and are therefore always at the pressure of the air around. At a closed end they

can and do undergo changes of pressure. The mouth and an open end are always the middle of a loop, while a closed end is always a node (*cf.* Fig. 23, p. 51).

It will further be noticed that the half, three-quarters, and whole-length tubes can be regarded as made up of two, three, or four quarter-length closed tubes, placed back to back, or face to face.

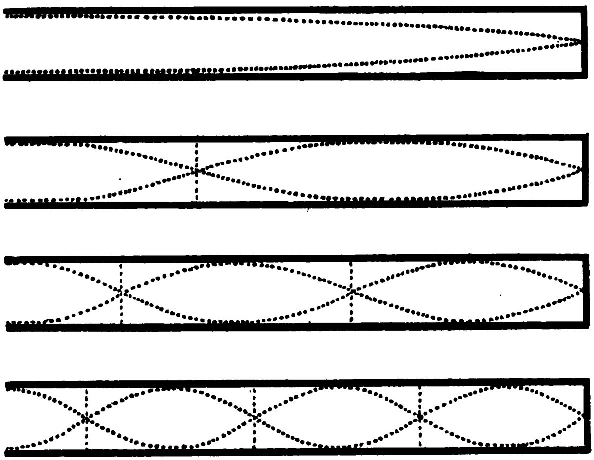


FIG. 24.—NOTES WHICH RESONATE WITH A CLOSED TUBE OF FIXED LENGTH.

The four figures show that a closed tube will resonate with waves four times, four-thirds, four-fifths, and four-sevenths the length of the tube.

If we now consider the length of the tube fixed (see Fig. 24), and inquire what are the lengths of the waves which can resonate in such a tube, we shall see that for closed tubes waves four times, four-thirds, four-fifths, and four-sevenths the length of the tubes can resonate. These waves are in the proportion $4 : \frac{4}{3} : \frac{4}{5} : \frac{4}{7}$, which is the same as $1 : \frac{1}{3} : \frac{1}{5} : \frac{1}{7}$. Now,

the frequency of a wave is inversely as its length (Chapter II.), therefore the frequency of the waves which resonate in a closed tube are as $1:3:5:7$; these are the alternate odd overtones of the prime note. If our tube is 1 foot long, it will resonate with middle C and also with its odd overtones.

Similarly, by examining Fig. 25, we shall see that

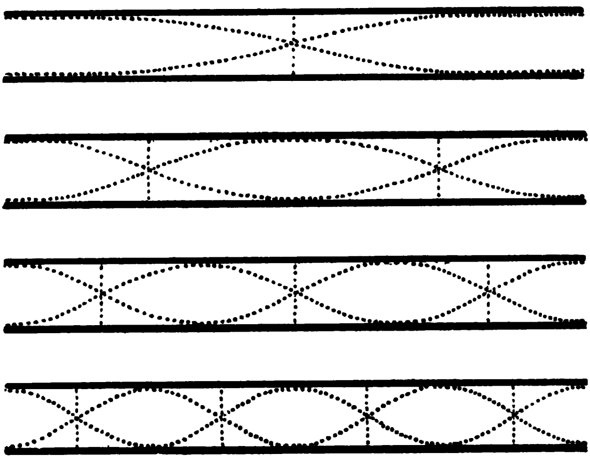


FIG. 25.—NOTES WHICH RESONATE WITH AN OPEN TUBE OF FIXED LENGTH.

The four figures show that an open tube will resonate with waves twice—the same, two-thirds and half its length.

the lengths of the waves that can resonate in an open tube are twice its length, the same length, two-thirds its length, and half its length. These are in the proportion $2:1:\frac{2}{3}:\frac{1}{2}$, which is the same as $1:\frac{1}{2}:\frac{1}{3}:\frac{1}{4}$. The frequency of these notes will be as $1:2:3:4$—that is to say, all the overtones of the prime note are present.

It will further be noticed that the prime tone of the closed is an octave below that of the same tube when open; a 1-foot tube resonates with C when closed, with C^1 when open.

Finally, it will be seen that a tube when open will resonate to the overtones which the same tube when closed did not resonate with, the alternate even overtones. Thus, a 1-foot tube when closed will resonate with C, G^1, E^2, etc., and the same tube when open will resonate with C^1, C^2, G^2, etc.; these are the even overtones of the prime note of the tube when closed, but all the overtones of the prime note of the tube when open.

FIG. 26.—STOPPED ORGAN-PIPE.

Organ-pipes are practically open or closed tubes, and the notes they give are the lowest note the corresponding tube would resonate with. Thus, open organ-pipes can have all the overtones of the prime note, while closed pipes can only have the alternate overtones, consequently open pipes give a richer sound than closed pipes; but the open pipe for a given note has to be twice the length of the closed pipe for the same note. The open pipe for C_8 would be 16 feet long, and there may not be space for this. The difficulty can be got over by using an 8-foot 'stopped' pipe (Fig. 26). The diameter of a pipe has an effect on the overtones produced. A wide stopped pipe has no overtones at all; therefore a very pure tone is obtained from a wide stopped pipe, or by holding a tuning-fork over a wide closed resonator.

If to a nightingale-pipe a sliding wooden plug be fitted, we have in miniature an adjustable stopped organ-pipe. With this the reader can ascertain the shortest stopped pipe, of which he can hear the note. If, for instance, that length be $\frac{1}{4}$ inch, the wave-length will be 1 inch, which will give for sound travelling at 1,090 feet a second $1,090 \times 12 = 13,080$ vibrations a second (see Chapter II.).

CHAPTER V

'TIME' AND MOVEMENT

THE essence of poetry and of music, of marching and of dancing, is 'time'; by this is meant the dividing up of time into equal periods. In poetry these periods are called feet; in music bars or measures. The dividing and marking off of the equal periods may be effected in various ways. We will start with poetry.

In the English language in words of two or more syllables we lay more stress on one syllable than another; thus, in 'sléep-ing' we lay stress on the first syllable; in 'a-wáke' on the second. With words of three syllables, the accent may be on the first syllable, as in 'wáke-ful-ness'; on the second, as in 'a-lért-ness'; or on the third, as in 'pro-men-áde.'

Words of one syllable have no special accent, but some of them derive prominence from the fact that they take longer to pronounce than others; thus, it takes more time to say 'gold' than to say 'tin.'

Apart from this, emphasis is laid on certain words in accordance with their importance in a sentence; in 'I told you,' stress is laid on 'told,' and this is done by pronouncing it somewhat louder and somewhat longer. In asking a question, stress is laid on the concluding word by raising the pitch of the voice;

in 'Cannot you come earlier?' the word 'earlier' is pronounced in a higher pitch.

Thus, accent or stress can be laid on a syllable in three ways: by pronouncing it louder, by pronouncing it longer, or by altering its pitch, generally by raising it.

The difference between prose and verse consists in that while in prose the accented syllables come irregularly, in verse they come regularly either every second or every third syllable.

The following verse shows the regular sequence of the accented syllables:

> The hárp | that ónce | through Tá- | ra's hálls |
>   The sóul | of mús- | ic shéd,
> Now hángs | as múte | on Tá- | ra's wálls |
>   As íf | that sóul | were fléd; ||
> So sléeps | the príde | of fór- | mer dáys, |
>   So gló- | ry's thríll | is o'ér, |
> And heárts | that ónce | beat hígh | for práise |
>   Now féel | that púlse | no móre. ||*

It will be seen here that stress falls on certain syllables in three ways:

1. The word accent in words of two syllables, as 'músic,' 'fórmer,' 'glóry.'

2. From the length of the words when spoken; compare 'soul' and 'praise' with 'of' and 'is.'

3. By the importance of the words in the sense; compare 'mute' and 'o'er' with 'the' and 'as.'

The feet here consist of two syllables; the metre is therefore duple, and as the accent is on the second syllable of each foot, the verse is in rising duple metre.

There is also a falling duple metre in which the accent falls on the first of the two syllables in a duple foot; thus:

> Cóme and | tríp it | ás you | gó ||
> Ón the | líght fan- | tás-tic | tóe. || †

* Moore's 'Irish Melodies.' † Milton's 'L' Allegro.'

And :

Stráight mine | eýe has | caúght new | pleásures |
· Aś the | lándscape | róund it | méasures. || *

But the accent may fall on every third syllable, making triple metre :

Táke her up | ténderly, |
Líft her with | cáre, ||
Fáshioned so | sléndərly, |
Yoúng and so | fáir. || †

Or :

Cánnon to | ríght of them, |
Cánnon to | léft of them, |
Cánnon in | frónt of them, |
Vólleyed and | thúndered. || ‡

In these two examples the accent is on the first syllable of each foot ; the metre is therefore triple falling. But there is also triple rising metre, thus :

I have fóund | out a gíft | for my fáir, |
I have fóund | where the wóod- | pigeons bréed. | §

Or, again :

You may bréak, | you may shát- | ter the váse | if you wíll, |
But the scént | of the rós | -es will háng | round it stíll. || ¶

A certain number of feet go to make up a line, and the lines are arranged in verses, the whole constituting the metre of the poem. The metres used are many ; that of English heroic verse, in which 'Paradise Lost' and the plays of Shakespeare and other dramatists are written, consists of five feet of duple rising metre, thus :

Oh, thóu | art faír- | er thán | the éve- | ning aír, |
Clad ín | the beáu- | ty óf | a thóu- | sand stárs. || **

---

* Milton's 'L' Allegro.' † Hood's 'Bridge of Sighs.'
‡ Tennyson's 'Charge of the Light Brigade.'
§ Shenstone's 'Pastoral Ballad.'
¶ Moore's 'Irish Melodies.'
** Marlowe's 'Dr. Faustus.'

Or:

Like swéet | bells ján- | gled oút | of tuñe | and hafsh. || *

Or:

. . . . | ye biŕds |
That siñg- | ing úp | to heáv- | en-gáte | asceñd |
Bear ón | your wiñgs | and iñ | your notés | his praíse. || †

A writer of poetry uses the metre he thinks best suited to his subject; nor is he bound to keep constantly to the number of syllables. Too great regularity is 'faultily faultless'; while, on the other hand, too great roughness will lose for many readers the rhythm altogether.

We now pass to consider 'time' in connection with music. Here, too, time depends on equal periods, called, however, not feet, but bars or measures. The divisions are marked by accented notes, the accent being obtained by the player, who, feeling the rhythm, plays certain notes louder: that this is not the only method is shown by children being able to dance to a barrel-organ: time is also marked by a change of pitch and the ordered arrangement of longer and shorter notes. The bar is measured from the commencement of one accented note to that of the next; in other words, the bar always begins with the accented note. The time is nearly always duple, triple, or quadruple. In duple time there are two beats or pulses in the bar, with the accent on the first, as in the word 'mú-sic'; in triple time there are three beats, with the accent on the first, as in the word 'músical'; in quadruple time there are four beats to the bar, with the accent on the first, as in the word 'mús-i-cal-ly'; but if this word be pronounced, it will be found there is a second but lesser accent on the third syllable; in the same way, in

* Shakespeare's 'Hamlet.' † Milton's 'Paradise Lost.'

quadruple time, there is always a medium accent on the third beat ; further, in all three times there is a weak accent on the first note of the unaccented beats. And this is not quite all : in spoken words of many syllables there is a tendency to put accents on alternate syllables, as in the words 'répreséntatíve' and 'únpreméditáted'; and the same occurs in music when a beat consists of several notes. A little consideration will show that we may have bars containing the same number of the same notes, yet in different time ; a bar containing twelve quavers may be in duple time, corresponding to two dotted (one and a half) minims ; or in triple time, corresponding to three minims ; or in quadruple time, corresponding to four dotted (one and a half) crotchets. There is a great difference between these three, owing to the different position of the accents strong and weak ; in all three there would be a strong accent on the first quaver of the bar, but in the duple time there would be a weak accent at the commencement of the second beat, on the seventh quaver, and accents also on the alternate notes in each beat. In triple time there would be weak accents on the fifth and ninth quavers, and in quadruple time a medium accent on the seventh quaver, and weak accents on the fourth and tenth ; thus, we should get finally :

Duple time (compound) = 2 𝅗𝅥. :

Triple time (simple) = 3 𝅗𝅥 :

Quadruple time (compound) = 4 ♩. :

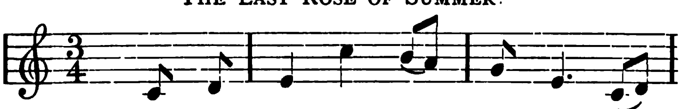
When the beats are composed of simple notes, the time is said to be simple; when of dotted notes, the time is called compound; but it is not the time that is compound, but the mode of writing the notes.

In setting songs to music, the simplest and most natural way is to put duple or quadruple music to duple or quadruple metre, and triple time to triple metre, at the same time giving the accented syllables to the accented notes; and this is often done.

In the song 'The Harp that Once,' the metre is duple; the music quadruple.

The air of 'The Last Rose of Summer' is in triple time, and the verses are in triple metre: thus:

THE LAST ROSE OF SUMMER.



Key C. {|: d . r | m : d' : t . l | s . m :—: d . r }
'Tis the last rose of sum - mer Left

{| m : f . m : r.,d | d : : d . r | m : d' : t . l }
bloom - ing a - - lone, All her love - ly com-

{| s .m:—:d.r | m : f.m : r.,d | d : ||

pan - ions Are fad - - ed and gone.

This simple relation between the metre of the poem and the rhythm of the music does not by any means always prevail; even when it occurs in the original it is apt to be lost in translations.

The bars in music are arranged in groups like the feet in lines in poetry, and the groups of bars in sets like the lines in verses. In 'God Save the King' the notes are in triple time, the bars are in pairs, and these pairs in sets of three or four; thus, the rhythm of the music fits the metre of the poem, as was only to be expected; but this arrangement of bars into groups, and these groups into larger groups, occurs also in music without words. In a waltz the bars of triple time are in sets of eight or sixteen.

Finally, we come to consider the relation between music and movement, marching and dancing. Man being a two-legged animal, his natural motion is duple, and all marches are therefore in duple or quadruple time; so also are many dances, such as quadrilles, lancers, polkas, and gavottes; on the other hand, waltzes, mazurkas, and minuets are in triple time. To show the connection between the steps and the music of the waltz, we have made the drawings Figs. 27, 28, 29, and 30. Each bar of music corresponds to a half turn, two bars to a complete turn; the steps of a half turn consist of (as shown) (1) a step with one foot; (2) a step with the other foot; and (3) a turning on the

balls of the toes of both feet. The first step commences with the first beat of the bar, but as the first step takes up half the time of the half turn, the second and third steps do not exactly correspond to the second and third beats. The time is taken from the first, the accented, note of the bar. See also the descriptions on p. 70 of Figs. 27-30.

FIG. 27.

FIG. 28.

FIG. 29.

FIG. 30.

DESCRIPTIONS OF FIGS. 27–30.

FIG. 27.—BOY AND GIRL WALTZING.

Shows the position before starting. The girl is carrying her weight on the left foot, the boy on the right.

FIG. 28.—BOY AND GIRL WALTZING.

The first step. The girl advances the right foot, and transfers her weight to it. The boy advances his left foot, and transfers his weight to it.

FIG. 29.—BOY AND GIRL WALTZING.

The second step. The girl swings round her left foot, keeping her weight on the right, and slightly turning on it. The boy swings round his right foot, keeping his weight on the left.

FIG. 30.—BOY AND GIRL WALTZING.

The third step. No actual step is taken, but the dancers turn on the balls of the toes of both feet, changing completely the positions of the heels, but only slightly that of the toes. It will be seen that the fourth position is precisely the reverse of the first. The second half of the whole turn is the same as the first half reversed.

In all four drawings the ground-plan of the feet is drawn below the figures. The light-coloured feet are the girl's, the dark the boy's. The drawings of the feet show on which foot the weight is being borne by the heel being down and shaded.

CHAPTER VI

THE EAR

THE ear consists of (1) the external ear or auricle, (2) the auditory canal, (3) the membrane of the drum,

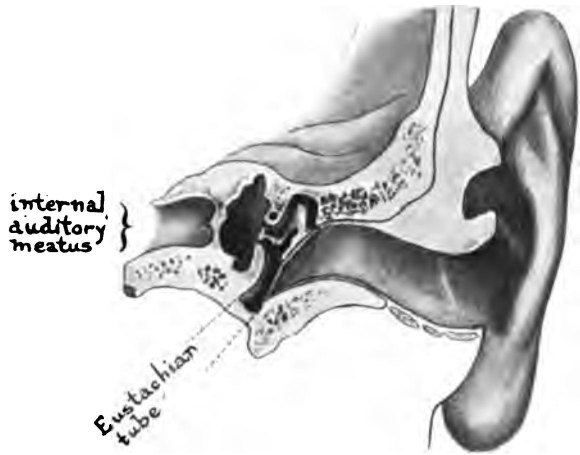


FIG. 31.—SECTION OF LEFT EAR (NATURAL SIZE).

It shows auricle, external auditory canal, membrane or drum-head, handle of hammer-bone attached to the membrane, the cavity of the drum or tympanum, with the Eustachian tube leading out of it, the chain of small bones crossing it, the labyrinth sawn across, and the internal auditory canal which contains the nerve of hearing.

(4) the drum, (5) the chain of small bones crossing the drum, (6) the internal ear, (7) the auditory nerve (Fig. 31).

1. *The Auricle.*—In many of the lower animals—in horses, for instance—the auricle is freely moved in different directions to collect and direct the sound down the auditory canal; in man this power appears to be lost; with us the auricle is merely an ornament.

2. *The External Auditory Canal.*—It is a great advantage that the most important and delicate part of

FIG. 32.—DRUM OF EAR (MAGNIFIED SIX TIMES).

The left drum-head as seen by looking down the external auditory canal with reflected light. The handle of the hammer-bone is seen, and below it a ray of light due to the shape of the membrane.

the ear is deeply placed in the skull, as it is thus more out of the way of injury, much more than is the eye.

3 and 4. A drum in its simplest form is a membrane stretched across the mouth of a cavity; the drum (or tympanum) of the ear then consists of two parts—(3) the tympanic membrane, and (4) the cavity of the drum (see Figs. 31 and 33. The tympanic membrane closes the inner end of the auditory canal; internal to it is the cavity of the drum containing air.

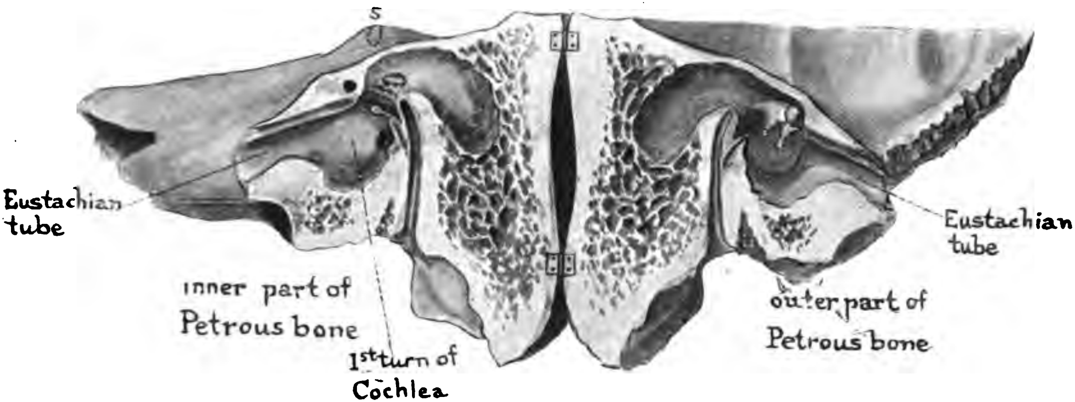


FIG. 33.—PETROUS BONE SAWN ACROSS (NATURAL SIZE).

The most important parts of the ear are placed in the substance of the petrous bone of the skull. This is shown sawn through, and the two halves turned back and joined together again by hinges (the saw is made to pass through the cavity of the drum, between the anvil and stirrup-bones). On the outer part (right-hand side of drawing) are seen the Eustachian tube leading into the cavity of the drum, the inner side of the membrane of the drum, the hammer and anvil bones. Behind the bones is an air cavity, called the antrum. On the left-hand or inner side are seen the Eustachian tube again, also the inner wall of the cavity of the drum formed by the outer wall of the labyrinth. Only the top of the stirrup-bone is seen in the oval window. The white-looking thread proceeding from it is a muscle. Below this muscle is the round window: it looks oval, because it is seen sideways. The dotted oval marked S is the superior semi circular canal; that below this the external canal (see Fig. 36). The saw passes through a vertical canal, which is therefore seen on both sides. This canal contains an important nerve, but not the auditory nerve, with which we are chiefly concerned.

5. Across the cavity of the drum stretches, from the membrane externally to the internal ear internally, a chain of three small bones—the hammer (or malleus), the anvil (or incus), and the stirrup (or stapes). The hammer-bone has a 'handle' which is embedded in the tympanic membrane. At the other end of the chain the footpiece of the stirrup fits into an oval window in the internal ear (Figs. 31, 40).

From the front part of the cavity of the drum there passes to the throat a canal—the Eustachian canal, so called after the anatomist Eustachius (died 1574), who first described it. The inner trumpet-shaped opening of the Eustachian tube is seen in Fig. 47. The effect of this tube is to keep the air pressure on the inner side of the membrane of the drum equal to that on the outside. If from any cause (such as a bad 'cold') the inner end of the Eustachian tube is closed, no fresh air can enter to take the place of that which is constantly being slowly absorbed from the cavity, the pressure therein is thus diminished, the membrane drawn in, and with it the chain of ossicles, and a certain amount of deafness results. However, the reopening of the tube, which occurs when the swelling in the throat subsides or may result simply from the act of swallowing, will allow air to enter the drum, and the deafness may immediately pass away.

6. The internal ear, which is also called, on accouut of its complicated shape, the labyrinth, consists of two parts, the cochlea or shell, and the semicircular canals, three in number. These last are thought not to play any part in hearing, but to be concerned in informing us of our position in space; thus, if by turning round rapidly we make ourselves giddy,

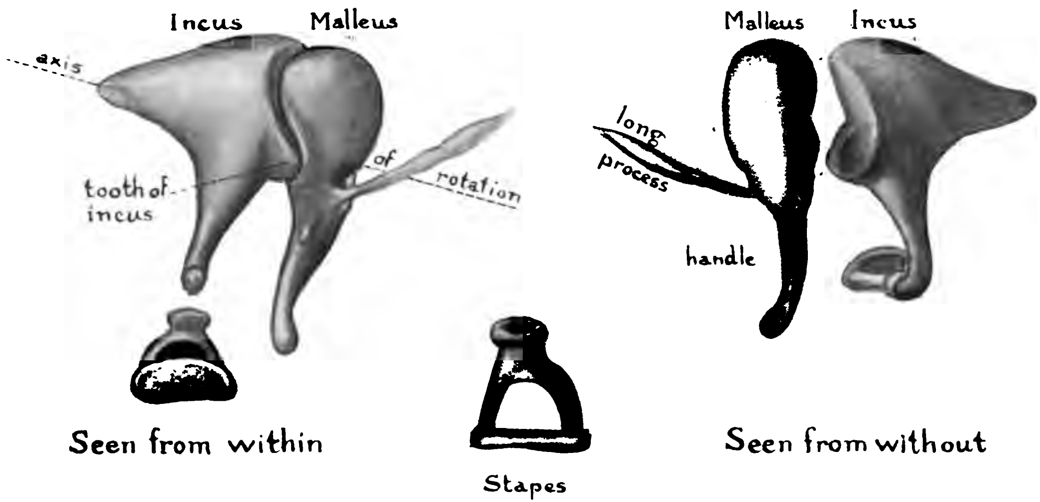


FIG. 34.—SMALL BONES OF EAR (MAGNIFIED FIVE DIAMETERS).

The three small bones of the left ear (magnified five diameters)—namely, the malleus (hammer), the incus (anvil), the stapes (stirrup). The important tooth of the incus is seen (see text).

our semicircular canals are temporarily confused (Figs. 36, 37).

The cochlea, on the other hand, is the most important

FIG. 35.—TO SHOW SITE OF LABYRINTH.

The inner half of petrous bone (Fig. 33) to show the position in it of the labyrinth (compare with Fig. 36).

part of the organ of hearing ; it is, as its name implies, like a shell coiled on itself. It can be studied in two

FIG. 36.—LABYRINTH.

The labyrinth, showing the cochlea or shell to the left, and the semicircular canals. There is seen also a groove (for a nerve), and below this the oval window (oval, because it has to fit the footpiece of a stirrup). Below this, again, is seen the round window: it looks oval merely because it is seen sideways.

ways, either by a vertical section, or by supposing it to be uncoiled (Figs. 38, 39). Up the centre of the cochlea passes a vertical column, the modiolus, and

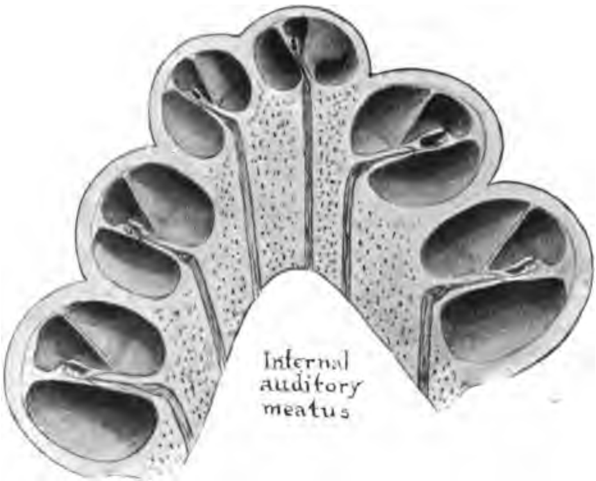


FIG. 37.—TRANSVERSE SECTION OF COCHLEA.

Transverse section of the cochlea or shell, showing the coils in section. Notice that in the uppermost coil the scala cochleæ ends in a blind end like the finger of a glove. The small canals, along which the nerve fibres pass from the organ of Corti through the bone to the internal auditory meatus, where they unite to form the auditory nerve, are well seen.

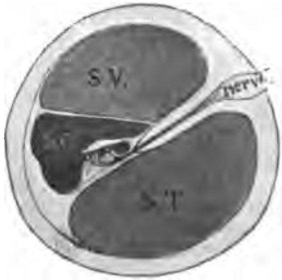
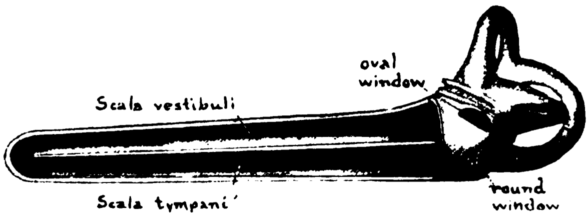
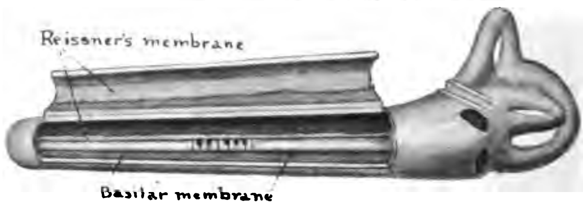


FIG. 38.—SECTION OF ONE COIL OF COCHLEA.

Transverse section of one coil of the cochlea. Above is the scala vestibuli, below the scala tympani, between them the scala cochleæ. It is on the membrane separating the scala cochleæ and the scala tympani that the most important part of the ear—that which transforms the vibrations of sound into nerve impulses—namely, the organ of Corti—is situated. The nerve passing from the organ of Corti towards the brain is marked. S.V., scala vestibuli; S.C., scala cochleæ; S.T., scala tympani.





FIGS. 39, 40, AND 41.—LABYRINTH UNROLLED.

To show what the labyrinth might be expected to look like if the cochlea (shell) could be unwound. In Fig. 39 the scala vestibuli and the scala tympani are seen separated by the bony ridge, the lamina spiralis. The former communicates with the oval window; the latter with the round window. In Fig. 40 the stirrup-bone is seen fitting into the oval window, also the three separate scalæ as described under Fig. 38. In Fig. 41, as in Fig. 40, a lid has been supposed to be cut and turned back, but in the latter figure the cut is carried lower, and Reissner's membrane divided so as to expose the organ of Corti on the basilar membrane. The basilar membrane is composed of rods, which are supposed to act like the strings of a piano do when the dampers are raised by pressing down the loud pedal —that is to say, resonate each to its particular note when sounded. Over the rods are certain hairs, shown in Fig. 38. Lastly, over the hairs is seen in the section (see also Fig. 38) a flap which runs the whole length of the basilar membrane. This is called the membrana tectoria. It is supposed to act somewhat as the dampers of a piano do, stopping the vibrations by pressing on the string. To indicate the supposed action of the organ of Corti, instead of it as shown in Fig. 40, there has been drawn in Fig. 41 the keyboard of a piano. The bass part of the organ of Corti is generally supposed to be at the top of the shell, the treble part at its base.

round this central pillar there winds spirally a bony ridge, the lamina spiralis. This ridge only reaches half way across to the outer wall of the cochlea, but the rest of the distance is bridged by two membranes, the upper, called Reissner's membrane, and the lower, the basilar membrane. These two membranes and the bony lamina thus divide the cavity of the cochlea into three spiral canals—the canal (or scala) of the vestibule, the canal of the cochlea or middle canal, and the canal of the tympanum. The canal of the vestibule opens at its lower end into a space called the vestibule, hence its name, and at its upper end communicates freely with the canal of the tympanum ; this latter at its lower end is nearly blind. The middle canal, or duct of the cochlea, is nearly or quite blind at both ends.

7. The nerve of hearing starts from the basilar membrane in numerous fine strands, which collect together into one nerve, which proceeds by the internal auditory canal to the brain.

Such, then, is the structure of the ear. How does it work ?

What the ear has to do is to convert the air vibrations reaching it into nerve impulses to be carried by the nerve of hearing to the brain ; the ear is a transformer.

The vibrations reaching the tympanic membrane are transmitted directly to the handle of the hammer, which is imbedded in the membrane. The handle then causes the head of the bone to move, the head passes the movement on to the anvil, which in turn causes the stirrup to move in and out of the oval window.

There are two points to be noted about this

mechanism. Firstly, that by the tip of the handle of the malleus moving through a much greater distance than the footpiece of the stirrup does, more force is given to the vibràtions; secondly, the structure of the joint between the hammer and anvil bones. From the inner side there is seen a projecting tooth on the anvil, which fits on to a corresponding surface of the hammer (Fig. 34); it results that when the hammer swings in it pushes the anvil before it, but when the hammer swings out the anvil need not follow more than a short distance, the joint then unlocking. The effect of this is that the footpiece of the stirrup-bone cannot be dragged out of the round window by too violent changes in the outer air; there is not the same danger of the stirrup being forced in too far, because the tympanic membrane is always concave, and the effect of strong pressure is only to make it taut.

Thus the vibrations reaching the tympanic membrane are carried to the oval window. As the walls of the cochlea are rigid, and the fluid within it incompressible, the footpiece of the stapes could not move in unless there was something to give way; the membrane at the round window does this. When the stapes goes in this membrane bulges out, and *vice versâ*. The waves from the oval window must reach the round window either by passing across through Reissner's and the basilar membrane, or by passing up the canal of the vestibule and down by the canal of the tympanum, or in both ways. In any case they will affect the basilar membrane, and cause it to vibrate either in whole or in part, but which? Do vibrations of any frequency cause the whole membrane to vibrate, or do vibrations of (say) 1,000 a second

cause one part to vibrate, and vibrations of 2,000 a second another part ?

This is an important question, but before attempting to answer it there are one or two points which should be considered.

The force in a single impulse of these sound vibrations is very slight; they only acquire any degree of force by repetition, by being able to get a swing up. A simple example will show what is meant. Let us take a slanting beam, and suspend from it by separate

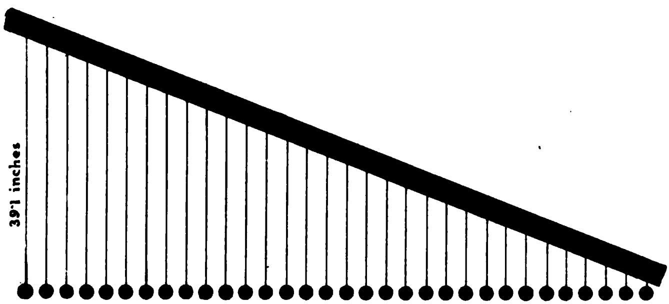


FIG. 42.—BEAM WITH PENDULA.
For description, see text.

strings a row of bullets. Further, let the length of the longest string be 39·1 inches, then this bullet will, if set swinging, act as a pendulum, and swing once each way in one second (Fig. 42). Now let us take a long lath, and give a tap to all the bullets with it; it will set them swinging very slightly. If, further, we give a tap every second a swing will be got up on the pendulum which beats seconds, and also on the bullet which would swing twice in a second, also on that which would swing three times in a second, and so on; but the intermediate bullets would not get up any

swing, as they will be retarded by some taps though helped by others. The series, once a second, twice, three times, and so on, is our old friend the harmonic series. Now, if instead of giving a succession of taps, we take in thought a huge bellows which blows for half a second in one direction with gradually increasing and then gradually diminishing force (varying just as the pace a pendulum moves at varies), and then sucks back in the same way for another half-second, we should get up a swing on one pendulum only—namely, the one-second pendulum. Similarly, if the bellows took only half a second over its double action, there would be a swing got up on the half-second pendulum and no other. The best wave to make a pendulum swing is its corresponding pendular wave, for it acts on it all the time, always in the right direction and always with the right strength, but this wave will only make its own particular pendulum swing.

It is supposed that in the internal ear there are vibrators which act like miniature pendula. If this is so a pendular wave—that is, a pure tone—would make its own particular vibrator vibrate and no other.

It has been already seen that pure tones sounded together produce a compound note. It does not follow from this that all compound notes consist of pure tones and no others ; still, as a matter of fact, they do. Consequently, when a compound tone reaches the internal ear, it makes all the vibrators corresponding to its pure tones vibrate. Thus the compound note $C_{|}$ would make the vibrators $C_{|}$, C, G, $C^{|}$, $E^{|}$, $G^{|}$, etc., vibrate if each of these tones was present in the note.

These vibrators will each disturb the nerve fibre

connected with itself, which, passing up through the nerve of hearing, will inform the brain.

If this is so, it would seem at first sight that what we should hear would be the several pure tones, and not the compound note. The probable explanation is that what we hear depends in great part on what we are in the habit of attending to. When spoken to, we listen for the gist of what is being said, not so much for the exact words, not for the notes and noises making up speech, and, least of all, for the tones making up the notes. Still, if in a compound note an overtone specially listened for can sometimes be heard. When present overtones can be well heard if a corresponding resonator be held to the ear; indeed, it was by this means that the overtones were investigated.

It is conceivable that a compound note might make the vibrator corresponding to its own wave-length vibrate, even if the pure tone of that wave-length were not present in the note, just as the nonpendular blows from our lath could make the pendulum swing; it must depend in part on how much swing is required. If the tones C (256) and G (384) were sounded together, they would produce a compound wave of frequency C_1 (128); but if the notes C and G are struck on the piano, C_1 will not be heard. Still, as already stated, difference tones can be sometimes heard (p. 44), but it does not follow that they are due to nonpendular waves (see Figs. 43, 44, 45, and 46).

If several tuning-forks are taken, and one is struck and the others held, one after another, close to it, it will be found that the vibrating fork can start sounding a fork the same as itself but no other. It is generally held that this is what occurs in the ear, but it has been

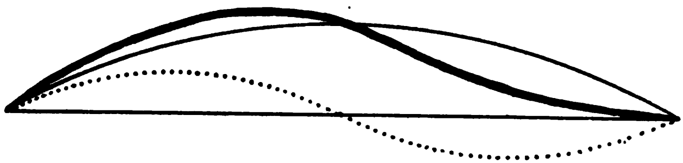


FIG. 43.—NOTE AND OCTAVE: RATIO 1 : 2.

A note (thin continuous line) and its octave (dotted line) of twice its frequency and half its wave-length. The resulting compound note is shown by the thick line.

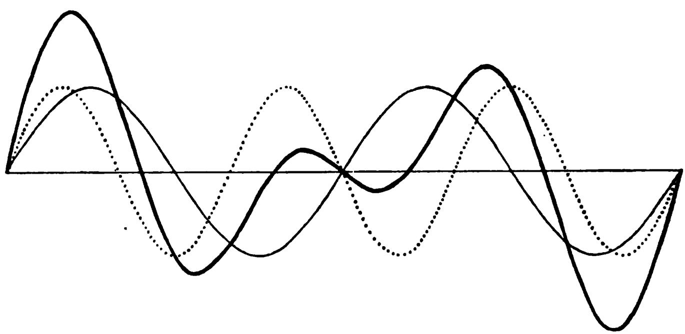


FIG. 44.—NOTE AND 'FIFTH': RATIO 2 : 3.

A note (thin continuous line) and its 'fifth' (dotted line) of $\frac{3}{2}$ frequency and $\frac{2}{3}$ wave-length. The resulting compound note is shown by the thick line.

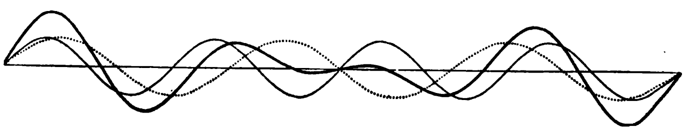


FIG. 45.—A NOTE AND 'FOURTH': RATIO 3 : 4.

A note (dotted line) and its 'fourth' (thin continuous line) of $\frac{4}{3}$ frequency and $\frac{3}{4}$ wave-length. The resulting compound note is shown by the thick line.

suggested that the internal vibrators act, not like tuning-forks, but like stretched strings, and are able to be started, not only by vibrations of their proper frequency, by their first overtone that is, but also by their other overtones. If it is so, it will explain very well one of the most striking facts connected with music—the close resemblance between a note and its octave.

There is quite another reason for thinking that different parts of the ear are affected by notes of different pitch. It is this—if a shake is executed first in the bass and then in the treble on the piano, it will be noticed that the sounds in the bass run much more into one another than those in the treble do. This is not due to the construction of the piano, for it occurs on all instruments; it is apparently due to the damping action of the part of the ear which receives the bass notes being slower than that for the treble part.

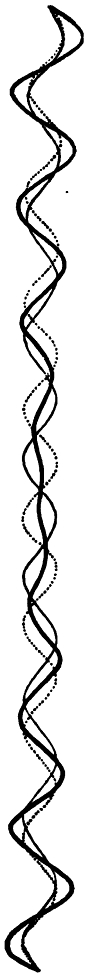


FIG. 46.—NOTE AND MAJOR TONE: RATIO 8 : 9.

A note (thin continuous line) and its major tone (dotted line) of $\frac{9}{8}$ times its frequency and $\frac{8}{9}$ times its wave-length. The resulting compound note is shown by the thick line.

If the distinguishing between notes of different pitch does not take place in the ear, it must in the brain. In that case the auditory nerve would act like the line-wire of a telephone, and convey, not tones, but compound notes. In this case there would seem no need for the internal ear at all; the auditory nerve should start from the inner side of the

membrane receiving the vibrations, as the line-wire does from the telephone disc. Further, the auditory nerve might then be, like the line-wire, a single stout fibre instead of being, as it is, made up of hundreds of fibres.

The theory that the ear contains vibrators, each of which vibrates to tones of a certain frequency, was first propounded by Helmholtz in 1862; it has stood the test of time, and is now generally accepted as in the main correct. The reader should refer to Ellis's translation of Helmholtz's great work, 'Sensations of Tone.'

The structure of the organ of Corti, the essential part of the ear, will be found described and well drawn in Quain's 'Elements of Anatomy' and in Testut's 'Anatomie Humaine.'

CHAPTER VII

THE VOICE

VOICE is the sound produced by the vibrations of the vocal cords, modified by resonance in the cavities of the throat, mouth, nose, and face.

The vocal cords are situated in the larynx, just behind the prominence in the throat known as Adam's apple (see Figs. 47, 48). The two cords are, when merely breathing, widely apart; in singing or speaking they approach one another, leaving only a narrow chink. In this position the passage of air from the lungs throws them into vibrations which produce sound (see Figs. 49). The larynx, therefore, is a double reed instrument.

In the case of musical strings, we have seen that the pitch of the note produced depends on three things—the length, the tension, and the thickness of the string (p. 36). So with the vocal cords, the note produced in singing depends on the length, tension, and thickness of the cords. These are regulated by the action of the muscles of the larynx, which are under the control of the will.

In ordinary speech and in singing the lower notes of the scale the whole length, breadth, and thickness of the cords are used. As the voice ascends the scale

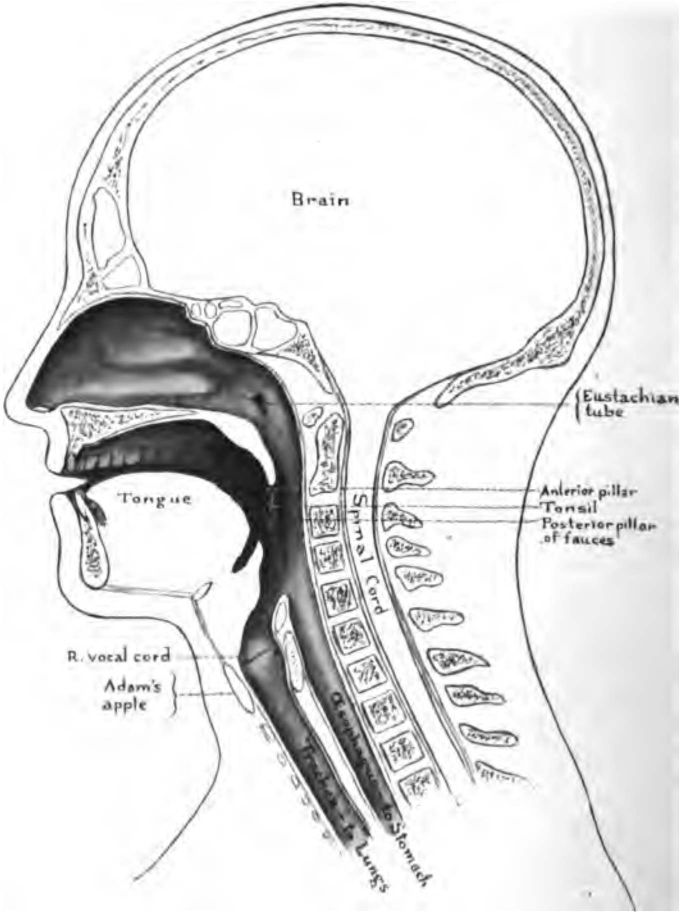


FIG. 47.—VERTICAL SECTION THROUGH HEAD AND NECK.

The cavities of the nose and mouth will be readily recognised. Behind the nose is seen the trumpet-shaped inner end of the right Eustachian tube in the throat. At the upper end of the trachea, or windpipe, is seen the right vocal cord. Behind the windpipe is the gullet, or œsophagus. The bones of the skull and neck are seen in section.

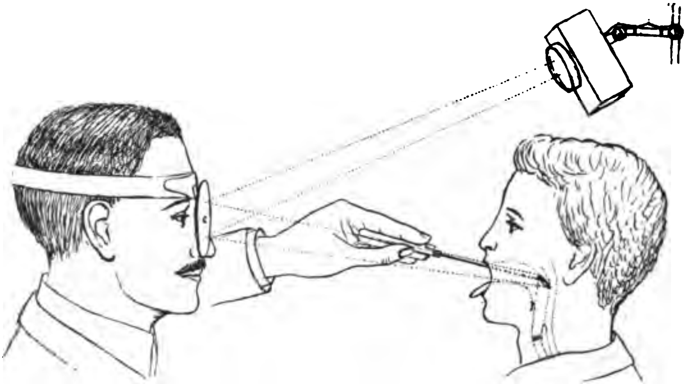


FIG. 48.—USE OF THE LARYNGOSCOPE.

The light from a lamp is reflected by a mirror on the forehead of the observer into the mouth of the boy. A small mirror the size of a shilling mounted on a long handle is placed at the back of the throat, so as to look towards the vocal cords. In this mirror is seen a reflection of the cords as shown in Fig. 49.

FIG. 49.—VOCAL CORDS AS SEEN WITH LARYNGOSCOPE.

The image seen in the small laryngoscopic mirror. Above is the extreme back of the tongue; next to that the epiglottis, which protects the vocal cords; below the vocal cords: these are seen as two white bands. In the left-hand figure the vocal cords are seen widely apart, as in breathing, and below them is seen the front wall of the windpipe. In the right-hand figure the vocal cords are seen brought together, as in singing a note. The laryngoscope was invented by Manuel Garcia, a distinguished professor of singing.

the higher pitch is obtained by increasing the tension of the cords by muscular action; but there comes a time when a higher pitch can no longer be obtained in this way, and then there occurs a sudden change in the mode in which the cords act. Instead of the whole breadth and thickness, only the thin edges of the cord vibrate; in this way a higher note is obtained.

The first method is called the thick register of the voice, because the whole thickness of the cords is used, and the second method the thin register, because only the thin edges of the cords are used. The point in the scale, the great break, where the change from the thick to the thin register occurs, is always, be it in men, women, or children, at or near the same point—namely, between the F and G of the middle octave, or near this.

In the thin register a further rise in pitch is obtained as before by an increase of tension, but here again a point is arrived at where the process can no longer be continued, and a new method becomes necessary. The change is now effected by only the anterior parts of the vocal cords vibrating, the posterior parts being brought into actual contact and not vibrating.

This method is called the small register of the voice, because only a part of the vocal cords is used. The point in the scale, the small break, where the change occurs, is always about the same place—namely, an octave above the great break—that is to say, between F^1 and G^1, or near that point.

The total range covered by human voices is about four octaves, from the F_2 of the deepest bass to the F^2 of the highest soprano. This latter note, F in altmo., occurs in the opera, 'The Magic Flute,' but it must be

remembered that the musical pitch was much lower in Mozart's time, making the note 1,350 vibrations per second instead of about 1,450 as now. The range of a single voice seldom exceeds two octaves, and is generally less.

THE MODELS.

The models are six in number—namely :

1. The outer half of that portion of the skull—the petrous bone—in which the ear is embedded.

2. The inner half of the same bone.

3. The labyrinth bone.

4, 5, and 6. The three small bones or ossicles of the ear.

The first three models are of natural size, but the three small bones have been enlarged five times linear. All the models, like all the drawings in the book, are of the left ear. The best way to study a model is to hold it, and think of it in the way it would go in one's own body.

MODELS 1 AND 2 (Compare Fig. 33, p. 73).

That part of the skull in which the ear is placed has been sawn across in such a way that the saw passed through the cavity of the drum or tympanum from before backwards, and through the joint between the anvil and stirrup bones. The hammer and anvil bones, therefore, remain attached to the outer half of the bone, and the stirrup-bone to the inner half. The saw-cut at the back of the bone has been made curved, so that the two halves can be the more readily fitted together in correct position.

MODEL 1.—It is not practicable in a model to make the external canal of the ear hollow. Its position can, however, be easily made out in the model by noticing that its outer end has been painted black, and that its inner end is covered by the drum or membrane, which will be known by its being coloured gray. On the inner side of this Model 1 will be seen,

in addition to this membrane, the two small bones—the hammer and anvil—attached together in their proper position. They are coloured green. It will be seen that the handle of the hammer-bone reaches down to the centre of the drum (compare Fig. 32, p. 72).

In front of the membrane is a groove, not coloured. This is the outer half of the Eustachian canal. The brown line just above this indicates the position of a muscle, with which we are not now concerned.

MODEL 2.—If this is fitted on to Model 1, the groove for the inner half of the Eustachian tube will be readily recognised. Above this, painted brown, is the muscle just spoken of. Behind this is the inner wall of the tympanum, made up mainly of the first turn of the cochlea. Behind this above is the oval window with the stirrup-bone. This is too small to be shown clearly in this model, but its position is indicated by green paint. Below this is the round window, painted black. On the inner and lower side of this bone are two deep grooves coloured blue. They are for a large vein. The red colour indicates the position of a large artery.

MODEL 3.—The labyrinth bone. It consists of the cochlea or shell and the three semicircular canals (see Fig. 36, p. 76). In the model another portion of bone containing the internal auditory canal is left attached. This will help to fix the position of this bone in Model 2 of the petrous bone. The first turn of the cochlea will be seen in Model 3, and its position in Model 2 can be made out by aid of Fig. 35.

MODELS 4, 5, AND 6.—THE THREE SMALL BONES OR OSSICLES (ENLARGED FIVE TIMES).

MODEL 4.—The malleus or anvil. The head and handle will be easily seen. The long process (seen in Fig. 34, p. 75) has been left out of the model, as it would have been so easily bent or broken. The saddle-shaped joint between the hammer and anvil bones should be noted.

MODEL 5.—The anvil-bone. Its head and its long process which connects with the stirrup-bone will be easily recognised. Note also the toothed process fitting against the ridge of the malleus.

Model 6.—The stirrup-bone. Its position in the ear can be made out by knowing that the straight edge of the foot-piece is its lower edge, and the convex its upper edge; also that the arm which is bent outwards like the hock in the hind-leg of a horse is the back arm of the stirrup-bone.

In addition to the models, the box contains a nightingale whistle fitted with a wooden plug, which may be used as suggested in Chapter IV. (p. 57).

The models, in a separate box, can be obtained from the publishers, or from Mr. Lapidge, 31, Charing Cross, London, S.W., price one guinea, post free.

It may be mentioned that a small siren whistle can be purchased for half a crown, and a pair of micro-telephones for about ten shillings.

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THE END

Baillière, Tindall & Cox, 8, Henrietta Street, Covent Garden.